



COMPREHENSIVE
Assessment
of water management
in agriculture

Research Report

1



Integrated Land and Water Management for Food and Environmental Security

F. W. T. Penning de Vries, H. Acquay, D. Molden, S. J. Scherr, C. Valentin and O. Cofie

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The Comprehensive Assessment of Water Management in Agriculture takes stock of the costs, benefits and impacts of the past 50 years of water development for agriculture, the water management challenges communities are facing today, and solutions people have developed. The results of the Assessment will enable farming communities, governments and donors to make better-quality investment and management decisions to meet food and environmental security objectives in the near future and over the next 25 years.

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Comprehensive Assessment Research Report 1

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F. W. T. Penning de Vries

H. Acquay

D. Molden

S. J. Scherr

C. Valentin and

O. Cofie

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The authors: Frits W.T. Penning de Vries, International Water Management Institute (IWMI), Southeast Asia Regional Office, Bangkok, Thailand; Herbert Acquay, Global Environmental Facility, Washington, D.C., USA; David Molden, IWMI Headquarters Office, Colombo, Sri Lanka; Sara J. Scherr, University of Maryland, and Forest Trends, Washington, D.C., USA; Christian Valentin, Institute de Recherche pour le Developpement (IRD) and IWMI, Vientiane, Laos; Olufunke Cofie, IWMI Africa Office, Kumasi, Ghana.

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Contents

Summary	v
Foreword	vii
The Status of Land and Water Resources for Food and Environmental Security	1
Land and Water Degradation and Food Insecurity: Processes and Management	18
Improving Land and Water Resources: Lessons Learned	31
Priority Actions	36
Development of Policies to Stimulate Food and Environmental Security: Priorities and Approaches	40
Issues and Approaches in Research	47
Glossary	53
Literature Cited	59

Summary

One of humankind's achievements has been the development of the ability to produce enough food for the largest global population ever. But a marked failure has been to ensure food security for everyone. An estimated 800 million people do not have access to sufficient food supplies, mostly in South Asia and sub-Saharan Africa. Areas with the greatest water loss and land degradation correspond closely with areas of the highest rural poverty and malnutrition, and food and environmental insecurity. Degradation of land and water resources increasingly threatens national and household food security in many parts of the developing world. Loss and degradation of water and land for agriculture are not universal, but are widespread and accelerating, particularly in developing countries. In these countries, degradation reduces options for our future and that of the next generation. Agro-ecological systems and societies have a threshold to degradation resilience, and collapse when natural resources are degraded too far, as had happened in the past.

Major concerns related to degradation are:

1. Loss of water for agriculture and reallocation to cities and industries.
2. Reduction in land quality in many different ways, leading to reduced food supplies, lower agricultural income, increased costs to farmers and consumers, and deterioration of water-catchment functions.
3. Reduction in water quality due to pollution, waterborne diseases and disease vectors.
4. Loss of farmland through conversion to nonagricultural purposes. The analyses presented focus on four major geographic zones: headwaters, plains, urban areas and coastal areas.

Fortunately, there are also "bright spots" where degradation has been reversed and food and environmental security have been restored. Lessons from such successful experiences suggest the following actions:

- Learn from bright spots—places where people have checked or reversed degradation.
- Set well-informed priorities through integrated analysis of problems and solutions.
- Develop a policy and institutional environment that enables appropriate management of land and water, provides strong and equitable public governance that secures the resource rights of food-insecure people, and creates incentives for investment in natural resources and for risk reduction.
- Target technology development and dissemination for food-insecure people.

New or updated national policies are also suggested to:

- Assess, update and monitor priorities for food security.
- Improve national capacity to promote effective and equitable use of natural resources, and support local initiatives.
- Strengthen or create institutions to plan and manage natural resources at basin and landscape scales, with all stakeholders.
- Develop mechanisms to value land and water quality, and provide more incentives for resource management.

With respect to research, this report identifies the following key areas:

- Evaluate the resilience of agro-ecological systems and their inhabitants to resource degradation, and quantify the associated critical thresholds.
- Assess the current status of land and water degradation, resource improvement, and food security, at subregional, regional and global scales.
- Develop management technologies to improve land and water productivity in

marginal agricultural lands, at farm and landscape levels.

- Develop and promote more sustainable aquaculture at farm and landscape levels.
- Develop systems for the large-scale recycling of nutrients in food and in waste transported from rural areas to cities and rivers.
- Develop mechanisms to internalize the off-site effects of degradation, and transfer financial resources from city dwellers and industrial users to upland farmers and water managers who provide water-catchment services.

Foreword

At the 1992 United Nations Conference on Environment and Sustainable Development in Rio de Janeiro, Brazil, world leaders committed themselves to an international agenda on environment and sustainable development, known as Agenda 21. Priority program areas outlined in Agenda 21 included support for the promotion of an integrated approach to natural resources management and for sustainable agriculture to improve food security. A decade later, world leaders are meeting again, this time in Johannesburg for the World Summit on Sustainable Development. However, food security continues to be one of the major challenges facing the world: approximately one person in six in the developing world does not have access to sufficient food to lead a healthy and productive life.

The aim of this document is to provide a basis for priority policy and research actions that will counteract the progression of degradation and will reduce its impact on household food security and the loss of other ecosystem services. Most of it was developed as a contribution to a background document for the Global Environmental Facility (GEF). As a Research Report, the document is now intended to raise the profile of land and water resources degradation, to present compelling arguments for further action, and to bring these concerns to public and government arenas. We intend to revisit this document with the feedback that we receive and with results of further analyses and case studies.

This document focuses on “land, water and food,” and in particular on the impacts of the degradation of land and water on food and environmental security. Within the sphere of “livelihoods” and “ecosystem services,” “food and environmental security” have been chosen as the target issue, not “poverty” per se. Yet, we need to understand their linkages and recognize the trade-offs between food security, ecosystem services,

the generation of global environmental benefits, and trade globalization.

There are many studies on water degradation, land degradation, and food and environmental insecurity. This report seeks to provide an analysis and to suggest recommendations that differ from those in the abovementioned studies in three ways:

1. *Integrated water and land analysis.* Most analyses have treated water and land issues separately. Yet the quality and flow of water resources is determined mostly by the management of land resources. By the same token, the productivity and sustainability of land resources are critically associated with water resources. Thus, the best results are to be obtained by managing both resources simultaneously within a landscape framework.
2. *Holistic, people-centered analysis.* Degradation-related food insecurity persists, despite considerable attempts to reduce it, because many interventions have been conceived in a too technical fashion. Holistic and people-centered approaches are required that treat land, water and food as components of the same system. The holistic approach focuses on the people who manage land and water and who suffer from food insecurity, thus highlighting the real constraints they experience, and providing more realistic targets for action.
3. *Focus on policy relevance.* Intervention strategies need to focus on those problems that have policy relevance: those that affect national, local, and farm-level food and environmental security and

agricultural development. This report suggests priority policy actions that may be relevant in many countries and

circumstances, and research issues that may help improve food and environmental security efficiently.

Integrated Land and Water Management for Food and Environmental Security

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The Status of Land and Water Resources for Food and Environmental Security

A Brief History

The publication *The Limits to Growth* by the “Club of Rome” (Meadows and Co-workers 1972) brought the broad realization that the quantity and quality of global natural resources are effectively limited, and that unbridled expansion of demands was simply unrealistic. Yet, famines in several countries underlined the rapidly growing need for food. Some researchers pointed out that much growth in demand can still be realized through much more efficient use of natural resources (e.g., Buringh et al. 1975).

Several major efforts addressed the issue of food insecurity in developing countries. In the 1960s, the world launched a major effort to improve food security in developing countries through large-scale agricultural-development programs under the banner of the green revolution. The main goal of these programs was to address food security at three levels. On the global level, the objective was to produce enough food to meet the full requirements of the world’s population. On the national level, the objective was to make enough food available to meet the demands of a nation. At the household level the objective was to ensure that households in urban and rural areas would be

able to produce or purchase the food that their members needed for a healthy and active lifestyle.

The large-scale agricultural programs had two main strategies. One strategy was intensification of agriculture to increase land and water productivity significantly through the introduction of high-yielding crop varieties, increased use of agrochemicals such as fertilizers and pesticides, and mechanization (use of tractors and other agricultural machinery). The other strategy was expansion of agricultural land area under irrigation. As a result of these efforts, the area of irrigated land in the world increased by 77 percent from about 153 million hectares in 1966 to 271 million hectares by 1998 (World Resources Institute 2000). The expansion of irrigated agriculture is not distributed evenly throughout the world: India and China account for about 41 percent of the world’s irrigated agricultural land, whereas Africa accounts for less than 14 percent (World Resources Institute 2000).

However, despite a tremendous contribution to food security, major intensive agricultural programs have also had unintended adverse impacts on the integrity and function of ecological systems, notably of agricultural

landscapes, forests, grasslands, freshwater bodies, and coastal and marine areas, that are critical for long-term global food security and for the livelihoods of people in the affected areas. Such impacts underscore the need for sustainable management of land and water resources to ensure long-term food and environmental security* (whenever there is an asterisk in the text please refer to the Glossary for a detailed description).

During the next two decades, the global population is projected to reach 7.5 billion. Most of this growth will occur in low-income countries. Cereal production in the developing world is projected to increase by 45 percent between 1997 and 2020; nonetheless, it will not keep pace with the increase in demand (Pinstrup-Andersen et al. 1999). Meat, root, oilseed and tuber products are all expected to increase by 40 to 80 percent over the same period, and with rising incomes, vegetable and fruit production will increase sharply. Meanwhile, nonfood agricultural production will also rise. All of these factors will increase pressure on a largely fixed land base. Future yield growth potentials are limited on high-quality croplands that are already being managed intensively, and will become even more limited if land degradation continues on irrigated lands. But in many areas, there is scope for improving the productivity of presently irrigated lands (Sakthivadivel et al. 1999), even if the cost of irrigation water increases. Moreover, much of the future growth is expected to come from lower-quality lands that will require substantial investment in land improvements and water utilization in order to sustain higher yields. Therefore, it is appropriate to introduce options for improved and sustainable productivity now, before every inch of land is used up.

Despite accelerating urbanization, rural populations in developing countries are projected to continue to grow until they reach a peak of about 3.09 billion in 2015; they may decline by 2025 to 3.03 billion. Thus increasing the

diversion of land and water to nonagricultural uses will also be essential to improve livelihood security for growing rural populations.

Most developing countries established public institutions to govern land and water resources many years ago, and have at least some targeted land- and water-conservation programs and policies. Some countries, such as China, have undertaken huge projects to combat land and water degradation. Donors and international development organizations have also supported land- and water-conservation programs to reduce downstream problems, increase agricultural productivity, reduce poverty or protect environmental resources in the degrading regions. While several billion dollars have been spent by organizations such as the World Bank, the Asian Development Bank and the International Fund for Agricultural Development (IFAD), these investments (except for the construction of irrigation projects) have generally represented less than 5 percent of agricultural spending, and less than 1 percent of total spending. Spending on these activities (watershed management, soil and water conservation, soil enrichment, etc.) is higher for organizations with a special focus on the rural poor such as IFAD (Sidahmed 2001), and for some bilateral donors such as the Swiss, who have concentrated on aid to mountainous or semiarid regions. Nongovernment organizations have implemented numerous community- and landscape-scale projects for land and water improvements as components of programs to reduce poverty and improve environmental conditions.

Intensification and social development processes have also led to considerable investment by local farmers and resource users in land and water improvement, using both indigenous and adapted technologies. For example, a review of 70 empirical studies on tropical hillsides found that in many places population growth, especially at higher population

densities, had led to extensive land-improving investment and conservation management (Templeton and Scherr 1999). Yet in many areas, the scale of land and water improvement is dwarfed by continued degradation. Past investments have been too modest, and many were not designed to meet socioeconomic conditions. Biot et al. (1995) recognized this as “institutional failure” and a lack of appropriate incentives to induce land users to adopt appropriate conservation technologies.

Consumption patterns across the world are very unequal. About 15 percent of the world’s population, in high-income countries, accounts for 56 percent of total consumption while the poorest 40 percent, in low-income countries, accounts for only 11 percent (World Bank 2001). Lack of access to sufficient food has had direct impacts on the nutritional status of millions of people in developing countries. From 1995 to 1997, 864 million people (18% of the total population of developing countries) were undernourished (International Commission on Peace and Food 2000). The situation is particularly urgent in sub-Saharan Africa, where the number of food-insecure people has doubled since the 1969–1971 period (Pinstrup-Andersen et al. 1999). Children have been the most vulnerable in countries facing food insecurity. In 2000, 182 million preschool children—33 percent of all children under the age of five in the developing world—were stunted or chronically undernourished, and 27 percent were underweight. Approximately 14 million children, most of them in developing countries, die each year from hunger-related diseases (International Commission on Peace and Food 2000).

Status of the World’s Ecosystems in 2000

The world’s land and water resources are critical for human survival. They provide goods such as

food crops, fish, livestock, and timber and nontimber products. They also provide ecological services such as purification of air and water, maintenance of biological diversity, and decomposition and recycling of nutrients (World Resources Institute 2000). Despite the emerging recognition of their central role in human survival, land and water ecosystems are being degraded at an alarming rate. This section provides a brief global overview of the status of three terrestrial ecosystems—agriculture, forests and grasslands—and two aquatic ecosystems—freshwater systems and coastal and marine systems; we will focus on land and water resources later in this report.

Agricultural ecosystem. The agricultural ecosystem or agro-ecosystem* refers to natural landscapes that have been modified by humans for agriculture. Agro-ecosystems cover about 25 percent of the world’s total land area, excluding Greenland and Antarctica. Together with mangrove forest and riparian lands, they account for 90 percent of all animal and plant protein and almost 99 percent of the calories that people consume (FAO 2000; World Resources Institute 2000). Around 40 percent of the world’s population of 6 billion people live in agro-ecosystems with irrigated and mixed irrigated/rain-fed agriculture, even though they occupy only 15 percent of the agricultural extent. Arid and semiarid agro-ecosystems, on the other hand, comprise around 30 percent of the agricultural extent, but they contain only 13 percent of the population (FAO 2001a; Wood et al. 2000, table 5). Globally, about 800 million people are food-insecure, of whom 300 million dwell in the semiarid tropics (Ryan and Spencer 2001).

About two-thirds of agro-ecosystems have been degraded over the last 50 years (World Resources Institute 2000). In these areas, unsustainable methods of land use are diminishing the agro-ecosystem’s ultimate capacity for agricultural production.

The main causes of ecosystem degradation are:

- Increased demand for food for a rapidly growing population resulting in intensification of agriculture and shortened fallow periods.
- Inappropriate agricultural policies such as ill-designed subsidies for water, fertilizers, and other agrochemicals, leading to wasteful use.
- Use of agricultural machinery and agronomic practices that are unsuitable for local soil and water conditions as well as the social and economic situation.
- Concentrations of livestock that lead to overgrazing in arid and semiarid areas, and to water pollution in wetter areas.
- Loss of natural vegetation that serves as buffers, waterway filters, dry-season fodder reserves and habitat.
- Poorly constructed infrastructure that leads to land fragmentation and erosion and disrupts hydrological systems.
- The inadequacy of legal frameworks for management of land and water in many countries, and shortage of implementing arrangements provide insufficient guidance for sustainable stewardship to allow for food and environmental security.

The adverse impacts of poor land management include soil, land and water degradation, and the loss of biodiversity through damage to habitat of wild species, including species such as pollinators beneficial to farming. The loss of crop-genetic biodiversity is evidenced in China, where the 10,000 wheat varieties grown in 1949 have been reduced to

300 varieties. Of these 300 varieties, only 14 are planted in 40 percent of the wheat fields under intensive farming systems (Halweil 2002).

Forest ecosystem. Forests cover approximately 33 percent of the world's land area, excluding Greenland and Antarctica (FAO 2001b). Recent estimates of forest coverage indicate that up to 50 percent of the world's original forest cover has been cleared already, and that deforestation continues. Deforestation of tropical forests alone is estimated at more than 130,000 ha/annum (World Resources Institute 2000). The two principal land uses that contribute to the degradation of forestlands are commercial logging and land conversion to agriculture.

The main causes of ecosystem degradation are:

- a. Growing demand for forest products.
- b. Policy failures such as undervaluation of timber stocks, which provide economic incentives for inefficient and wasteful logging practices.
- c. Agricultural subsidies that favor the conversion of forestlands for large-scale agriculture.
- d. Fragmented and weak institutional frameworks to support the conservation and sustainable use of forests.

The impacts of deforestation include land and water degradation, displacement of people, especially indigenous people who depend directly on the forest for their survival, and loss of biodiversity. Deforestation has also caused significant adverse hydrological changes to some of the world's major watersheds. Degradation of forests, including the setting of fires, accounts for about 20 percent of the world's annual carbon emissions (World Resources Institute 2000).

Grassland ecosystem. Grasslands cover approximately 52.5 million km² or 41 percent of the world's land area, excluding Antarctica and Greenland. Humans have modified grasslands significantly, in part by converting them for farming activities and urban development. Only 9 percent of grasslands in North America and 21 percent in South America are still intact, and more than 50 percent of the original grasslands of Asia, Africa and Australia have been lost (World Resources Institute 2000).

The main threats to the world's remaining grasslands are urbanization and conversion to agriculture, inappropriate use of fire to manage grasslands, and excessive grazing pressure from livestock.

The impacts of grassland degradation include the loss of biodiversity due to the conversion or fragmentation of habitats; soil degradation, particularly erosion due to the loss of vegetation cover; and soil compaction from high livestock-stocking densities. Finally, the burning of grasslands is a major contributor to carbon emissions. The burning of grasslands in Africa, for example, accounts for some 40 percent of carbon emissions from biomass burning each year (World Resources Institute 2000).

Freshwater ecosystem. Surface freshwater systems—rivers, lakes, and wetlands—occupy only 1 percent of the earth's surface area. Surface freshwater ecosystems face three major threats.

The first threat is fragmentation of rivers by structures such as dams, diversions and canals. Some 60 percent of the world's 227 largest rivers have been fragmented by these structures, resulting in the loss of biodiversity because of alteration of natural habitats. The Aral Sea has lost 20 of the 24 fish species that supported a commercial fishery because of water diversion and pollution from agrochemicals. As a result, the fishery, which had produced 40,000 tons of fish annually and employed 60,000 people, has

collapsed (World Resources Institute 2000). Dams have modified significantly sediment movement downstream to deltas, estuaries and floodplains. One result is significant decreases in floodplain agriculture (World Resources Institute 2000).

The second threat to freshwater ecosystems is excessive withdrawal of water. Approximately 70 percent of water withdrawals from nature are for irrigated agriculture, with the remainder being for domestic, industrial and hydropower uses. Withdrawal can lead to river desiccation or reduced flow during the dry season. Such a situation is already occurring in major river basins such as those of the Colorado, Nile, Yellow, and the Syr and Amu Darya rivers. Groundwater extraction is another form of freshwater withdrawal. This process contributes approximately 20 percent to global freshwater use, or as much as 600–700 km³ per year. Much of the groundwater comes from shallow aquifers that are fed by runoff. Another type of groundwater—fossil water—comes from deep sources that are not linked to the normal runoff cycle (World Resources Institute 2000). Groundwater is an important source of water for about 1.5 to 2 billion people. Some of the largest cities in the world, including Dhaka, Jakarta, Lima and Mexico City, depend almost entirely on groundwater as a source of drinking water (Sampat 2001).

Groundwater depletion occurs when water withdrawals are higher than natural recharge, resulting in a drop in the water table. In many of the most pump-intensive areas of India and China, water tables are falling at a rate of 1–3 m/year.

The third threat to freshwater ecosystems is pollution of surface water by agricultural chemicals, including fertilizers, pesticides and herbicides, animal wastes (especially from intensive livestock systems), and industrial chemicals. Groundwater can be polluted by nitrates and pesticides, mainly stemming from agriculture and industrial chemicals, sometimes

with heavy metals, from mining. In the United States, some 60 percent of wells sampled in agricultural areas in the mid-1990s contained pesticides (Sampat 2001; Revenga et al. 2000).

Coastal and marine ecosystem. Some 2.2 billion people, nearly 40 percent of the world's population, live within 100 km of a coastline. These people exert significant pressures on coastal and marine ecosystems that can affect the ecosystems' integrity and function adversely. These pressures include harvesting of natural resources, such as fish and mangrove forests; infrastructural development; and industrial, agricultural and household pollution. Coastal habitats or resources that are under severe threat from human activities include mangrove forests, coral reefs and fisheries.

Mangrove forests cover a total area of approximately 181,000 km² along the coastlines of 112 countries and territories, and approximately 50 percent of these forests have been destroyed in the past decades (Kelleher et al. 1995). The main threats to mangrove forests are excessive harvesting for fuelwood and timber, conversion to shrimp aquaculture, and development of urban and other types of infrastructures.

Most coral reefs occur in shallow tropical waters, and they cover about 255,000 km² of the earth's surface area. About 90 percent of the reefs are found in the Indo-Pacific Region (Spalding and Grenfell 1997). The main threats to coral reefs are land reclamation, coastal development and coral mining. Other human activities that can have indirect adverse effects on coral reefs are siltation and pollution.

Approximately 27 percent of coral reefs in the world have been degraded, and a further 32 percent may be under serious threat (Wilkinson 2001). Evidence is also emerging that the rise in both sea-level and temperature, associated with climate change, may threaten coral reefs. Sea-level rise will also have major effects on

extensive areas of coastal zones, some with major cities, with a very low elevation.

Fish are an important source of animal protein for people. They provide about one-sixth of the human intake of animal protein worldwide, and are the primary source of protein for about a billion people in developing countries. Fisheries are under pressure from overfishing. Overfishing occurs because of the excessive harvesting capacity in the world's fishing industry. According to one estimate, the level of fish harvesting exceeds a sustainable level by 30–40 percent. As a result, about 28 percent of the world's most important marine fish species have been fished near to or beyond the maximum sustainable yield (World Resources Institute 2000).

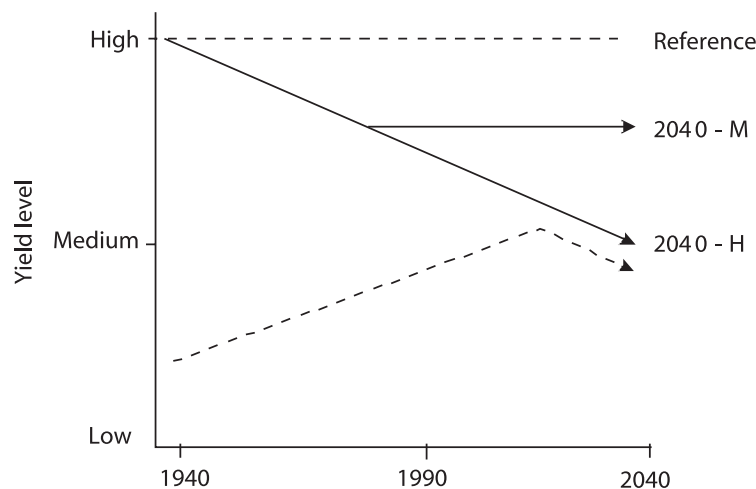
Global Patterns of Land and Water Degradation

Until recently, policymakers and policy analysts have not considered land and water degradation to be important threats to food security. It has been assumed widely that land is globally abundant and less important than other factors in determining agricultural productivity. Water has long been perceived to be important in relation to irrigation, but management of water on nonirrigated lands has been neglected. Moreover, there are common perceptions of the degradation of agro-ecological systems* as being a slow process that can be always reversed with adequate inputs. Yet such ecosystems are resilient* only up to a threshold, and will collapse when stressed beyond this level. One reason this goes unnoticed is that degradation invisibly lowers the capacity for production, while investments still allow actual production to go up, until the actual production level reaches a ceiling, after which both drop (figure 1).

Agricultural land resources in the developing world. One striking finding of a global

FIGURE 1.

Hypothetical example of how maximum yield level of crops (obtained in optimal biophysical conditions and used here as the reference yield level, per unit land or per unit water) gets reduced due to degradation.



Note: Two scenarios are shown: continuation of the current rate of degradation (labeled 2040-H), and a rate half as much (labeled 2040-M). The actual level of agricultural production (dotted line) rises in time due to intensification, until it approaches the potential level after which it must also decrease (after Penning de Vries 1999).

assessment of soil quality in agricultural areas is that only 16 percent of agricultural soils are free of significant physical and chemical constraints, such as poor drainage, poor nutrient status, poor tractability, salinity or alkalinity, or shallowness. Of these favorable soils, 60 percent are found in temperate areas, and only 15 percent in the tropics (Wood et al. 2000). The same source indicates that globally, 54 percent of the agricultural extent is "flat," 20 percent is on moderate slopes, 17 percent on steep slopes, and 8 percent on very steep slopes. All of these sloping lands are prone to high soil erosion and rainfall runoff, without adequate management. The agricultural land base in Africa is especially poor; most soils require careful management to maintain crop production, in addition to land-improving investments to raise productivity sustainably and to raise low input efficiency.

Agricultural land degradation. Land use, even intensive use, does not necessarily lead to degradation. Appropriate short-term investments

in inputs (water, fertilizer, seeds) and long-term investments in structures and equipment (pumps, tractors, dams, terraces) can conserve soil and water, while allowing productive and sustainable agricultural land use. The same applies to water: its use for growing crops does not have to lead to shortages and pollution. However, if conditions are such that farmers and livestock holders cannot invest in these inputs and structures, human activity will continue to degrade natural resources and livelihoods, unless off-farm employment can assist in providing an income without destroying the natural resources base. Societies and their institutions must invest for the long term in water- and land-management structures and in education to halt degradation.

Degradation has been taking place extensively for as long as agriculture has been practiced (Ponting 1991). It is difficult to quantify degradation because of the slow and very heterogeneous nature of the process. One guess is that as much land was degraded as was in production in 1960 (Rozanov et al. 1990).

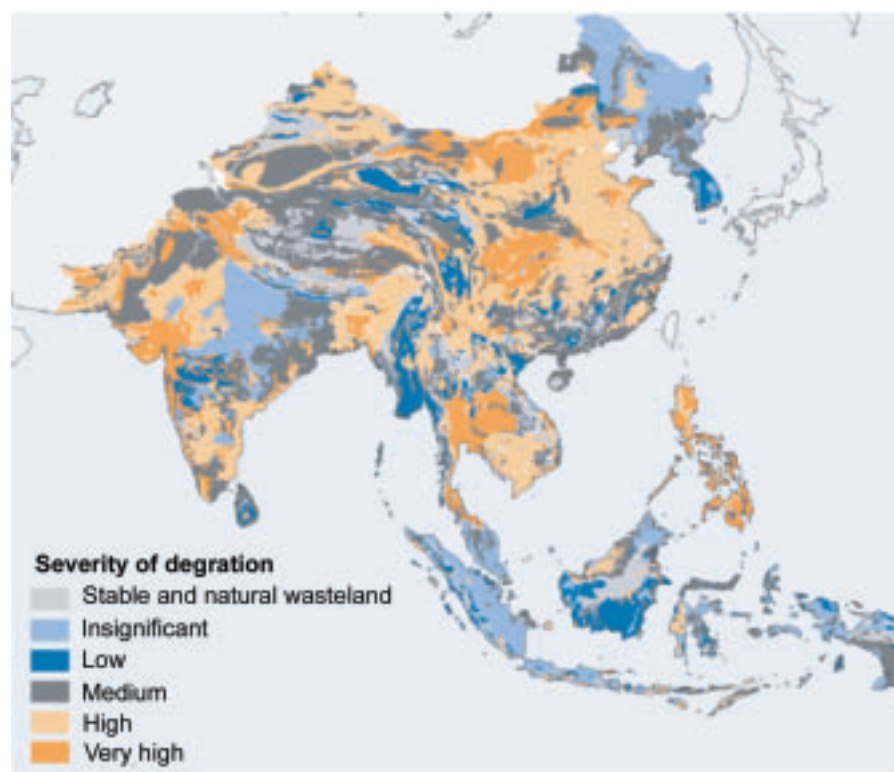
Results of a broad attempt to extrapolate data on degraded areas with more recent data and compare them with the total land area suitable for cultivation are presented in box 1 for three regions: East Asia and the Pacific (EAP), the Middle East and North Africa (MENA), and South Asia (SA) (regions as defined by the World Bank). This indicates that land is clearly a finite resource, and that in some regions all land suitable for sustainable agriculture is, in fact, already being used fully.

The degree of degradation is highly variable, and ranges from “complete loss” to “insignificant loss,” and in some cases “rehabilitation.” Wood et al. (2000) indicated that 40 percent of agricultural land in the world is moderately degraded and a further 9 percent strongly degraded, reducing global crop yield by 13

percent. An example of the degree of degradation for South and Southeast Asia is presented in figure 2. It is evident that degradation is widespread, and that its spatial variability is pronounced. At smaller scales of farms and catchments, heterogeneity is also very significant. The cost associated with remediation of environmental damage due to degradation can be very high (Rosegrant and Hazell 2000). For example, in Asia, its annual value has been estimated roughly at US\$35 billion (Jalal and Rogers 1997). This order of magnitude indicates a marked need to address erosion and other degradation problems through diverse means.

Degradation of water and land often occurs in parallel and it leads to a lower level of ecosystem services, in particular a reduced capacity for food production and income generation. Degradation is

FIGURE 2.
Global land degradation assessment for South and East Asia.

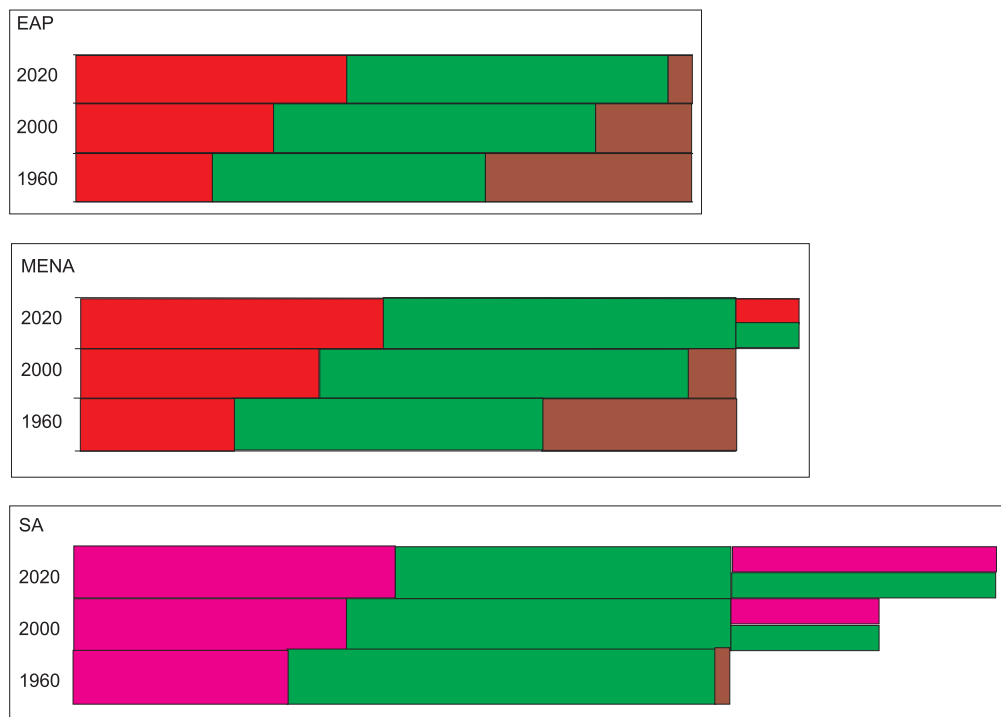


Source: Van Lynden and Oldman 1997.

Box 1. Declining Land Resources.

For every region, the full length of the bars represents the land surface that 5,000 years ago could have been turned into land that could be farmed productively and sustainably. In the process of cultivating and grazing the land, human beings have degraded land irreversibly. This and population growth have necessitated the opening up of new land. Opening new land and leaving degraded land behind is not unlike the process of “strip mining” that reduces the total amount of land resources. EAP stands for East Asia and the Pacific, MENA for Middle East and North Africa, and SA for South Asia.

Each bar shows the fraction of land suitable for sustainable agriculture that is still available (brown), the land surfaces currently in use for agricultural production (green), and the area fully degraded where recovery is uneconomical (red). For each region, three dates are shown: the lower bar depicts the situation in 1960, the middle bar the current situation, and the upper bar the scenario for the near future. The bar is split green/red when more land is “used” than is “available” for sustainable agriculture. Red reflects areas where “land” particularly influences “water” and green reflects areas where “water” particularly affects “land.”



Source: Penning de Vries 2001.

the result of inappropriate management. Degradation of these resources needs to be addressed as a single issue, and this will be done in the remainder of this report.

In an analysis of the Pakistan Punjab, Ali and Byerlee (2001) found that “Continuous and widespread resource degradation, as measured by soil and water quality variables, had a significant

negative effect on productivity. Degradation of agro-ecosystem health was related in part to modern technologies, such as fertilizer and tube well water, offsetting a substantial part of their contribution to productivity.”

Problems more or less specific to Africa should be recognized explicitly. These are caused by:

1. The extreme poverty of its resource base for agriculture, leading to low efficiencies of agricultural inputs and to overpopulation at low absolute population densities.
2. The need to intensify agriculture in situations where key infrastructure, such as roads, transport and distribution systems are not yet adequate and domestic markets are not a driver for change as yet.
3. Inadequate policies and bad governance.

Structural adjustments have obliged governments to retreat from direct participation in the agricultural inputs sector, but private-sector results have been discouraging. There are at least four reasons:

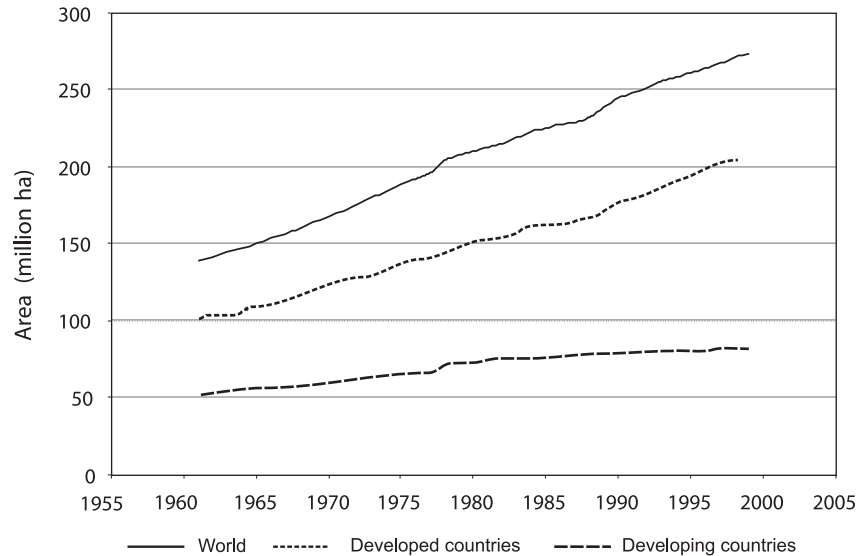
1. Retreat has yet to be completed in numerous countries.
2. Many countries lack transparent and competitive markets (government officials are still heavily involved in the business).
3. The impact of degradation processes results in reduced agronomic and economic productivity.
4. Farmers producing on low-quality or depleted soils lack complementary organic inputs and management practices to make use of chemical fertilizer effective and profitable. One of the consequences of recent policy shifts is that agricultural input use has not increased. Paradoxically, since the initiation of these structural adjustment programs, the average annual use of fertilizers in Africa has declined from 10 to 8 kg per hectare.

Freshwater resources in the developing world.

From 1900 to 1995, global withdrawals from river systems for human use have increased from 600 km³ to 3,800 km³ per year. Annual agricultural withdrawals are now in the order of 2,500 km³, or 70 percent of total withdrawals. In many developing countries irrigation withdrawals are over 90 percent of all water withdrawn for human use. From another perspective, of the 100,000 km³ per year reaching the earth's surface, only 40 percent reaches a river or groundwater storage and is considered to be a renewable water resource. Of this amount, some 3,800 km³ are now diverted from its natural courses, most of which (2,500 km³) is withdrawn for irrigation purposes (based on Shiklomanov 1999). The other 94 percent of the renewable resource is consumed in terrestrial, aquatic, and coastal ecosystems, and in rain-fed agriculture. Of the total evaporation from land surfaces, 15–20 percent results from rain-fed agriculture, and 5 percent from irrigated lands (estimated by overlaying World Water and Climate Atlas grids on the USGS land cover data set). Expansion of cropping in the past decades means that over 50 percent of the major river basins in South Asia, as in Europe, are now under agricultural cover; over 30 percent of the basin area is under agricultural cover in South America, North Africa, and Southeast Asia, as in the United States and Australia.

The interdependency of land and water management is even tighter for irrigation. The 17 percent of global cropland that is irrigated produces 30–40 percent of the world's crops. The share of cropland that is irrigated increased by 72 percent between 1966 and 1996. This does not include the widespread and growing use of small-scale irrigation systems providing supplementary water to mainly rain-fed cropping systems.

FIGURE 3.
Net irrigated area.



Source: FAOSTAT 2000 database.

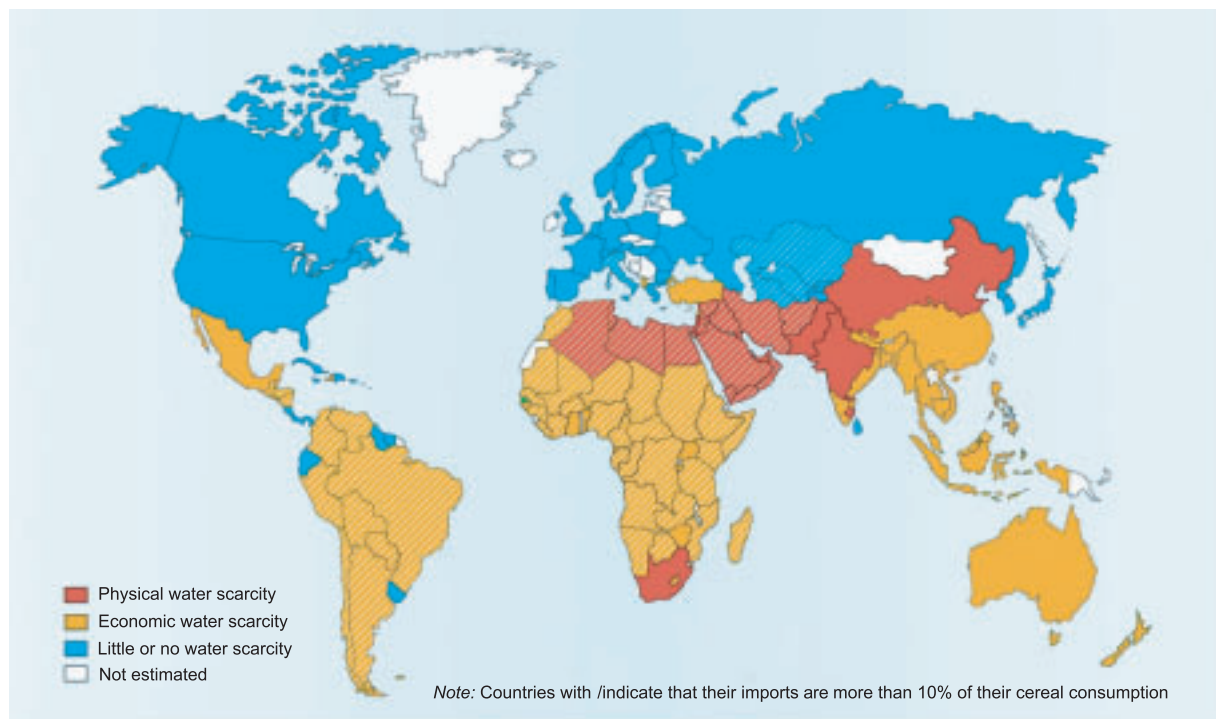
Water depletion and pollution. The expansion of irrigated and rain-fed agricultural areas, shown in figure 3, removes more and more water from natural uses, fueling depletion, pollution and competition for the resource. In many basins of the world, such as those of the Murray-Darling, the Colorado, the Indus, and the Yellow rivers, there is simply no more water for additional irrigation uses. In search for additional resources, farmers tap groundwater and wastewater for irrigation. In many breadbasket areas groundwater use has reached unsustainable levels. Competition for water between agriculture and urban interests is sharp. But on the whole, the conflict, or the need to find harmony or balance, is between uses of water in agriculture and uses of water for environmental flows that are important in sustaining ecosystem services. From this perspective, “how much irrigation do we really need?” is one of the burning questions of our times. How we resolve the world water crisis very much depends on how well water is managed in agriculture.

A global and first approximation of areas of projected water scarcity for biophysical or for economic reasons for 2025 is shown in figure 4.

Note that at any level of supply, there will be large fluctuations in time and space, so that this map is less significant for household water security than for national water and food security. Physically water-scarce areas are those that do not have sufficient water resources to meet agricultural, domestic and environmental needs by 2025. Areas with economic scarcity are areas where there are enough utilizable water resources to meet projected 2025 demands, but where much more water will need to be developed by a variety of means to meet additional demands. Most sub-Saharan African countries face an “economic” scarcity of water—where financial and human resources will constrain the ability to tap additional resources required. These are also areas of significant malnutrition.

Increasing the productivity of water in agriculture holds a key to solving water depletion and pollution problems. A common perception is that increasing efficiency in irrigation is the solution to the water crisis. Technically defined, efficiency tells us how much diverted water reaches the crops, and how much is wasted “down the drain.” But recent water accounting

FIGURE 4.
Water scarcity in 2025 if current trends continue.



Source: IWMI 2000.

studies demonstrate that especially in water-stressed basins, farmers are very effective in converting water for crop production (Molden et al. 2001; IWMI and GDRS 2000). Farmers as a group are often “too” efficient, in that little water is left for other human uses and environmental flows. But productivity per unit of water in many regions remains far below potential. Increasing the productivity of water will mean less water required in agriculture, easing pressures on strained water resources.

Poorly sited or mismanaged irrigation has led to salinization on about 20 percent of irrigated land. On an annual basis, about 1.5 million hectares are lost due to salinization alone, and about US\$11 billion in reduced productivity.

Intensification in high external input agro-ecosystems has often resulted in leaching of mineral fertilizers (especially nitrogen), pesticides, and animal-manure residues into

watercourses, due to inappropriate management or inadequate technologies (Barbier 1998). On more sloping lands with lower-quality soils, intensification has tended to increase soil erosion as well as the effects of sediment on aquatic systems, hydraulic structures and water usage (Wood et al. 2000).

Rain-fed agriculture. Rain-fed agriculture in developing countries in Africa, Asia, Latin America and the Pacific covers more than 90 percent of the total area of 36 million km². Of all countries, 70 percent depend on more than 60 percent of rain-fed agriculture (Rockstrom 2001). Thus, the management of rain-fed agricultural lands has a powerful effect on rainfall absorption, storage, runoff and water quality. Rainfall on these lands varies from place to place and year to year, but ranges from 600 to more than 2,000 mm/annum. In particular, the drier areas are

often used as rangelands. Crop yields on these lands also vary considerably. Even though the potential production on rain-fed land can be high (Penning de Vries and Djiteye 1982), actual yields are often less than 2 or 3 tonnes of dried food or feed per hectare, which value is less than half the average in irrigated lands. This implies that typical rainfall could support significantly higher production if good practices can be made attractive to farmers, e.g., by stabilizing yields and increasing input-use efficiency through micro-irrigation, diversification, insurance and regional cooperation.

Global Patterns of Food Insecurity

The geography of rural poverty. Food insecurity is associated closely with poverty. Approximately 1.2 billion people in the developing world are absolutely poor, with only a dollar a day or less per person to meet food, shelter and other basic needs. The World Development Indicator “Poverty” (World Bank 2001) provides a list of fractions of total national population below the national and international poverty line. Most of

the poor inhabit rural areas, but their numbers in urban areas are expanding rapidly.

The total rural population in the developing world in the mid-1990s was about 2.7 billion, of which about one-third lived on “favored” lands, defined as rain-fed or irrigated cropland in areas which are fertile, well-drained with even topography and with adequate rainfall. They have relatively low risk of degradation. The other two-thirds of the rural population either lived on “marginal” agricultural lands, defined as land currently used for agriculture, agroforestry and grazing, which have serious production constraints, or dwelt in forests, woodlands or arid lands. All these areas are especially prone to degradation without careful management. This is shown in table 1. The authors approximated rural poverty in the two areas by applying national percentages to the respective areas. The resulting estimates show that nearly 630 million of the rural poor live in marginal agricultural, forested and arid lands, and 320 million live on favored lands.

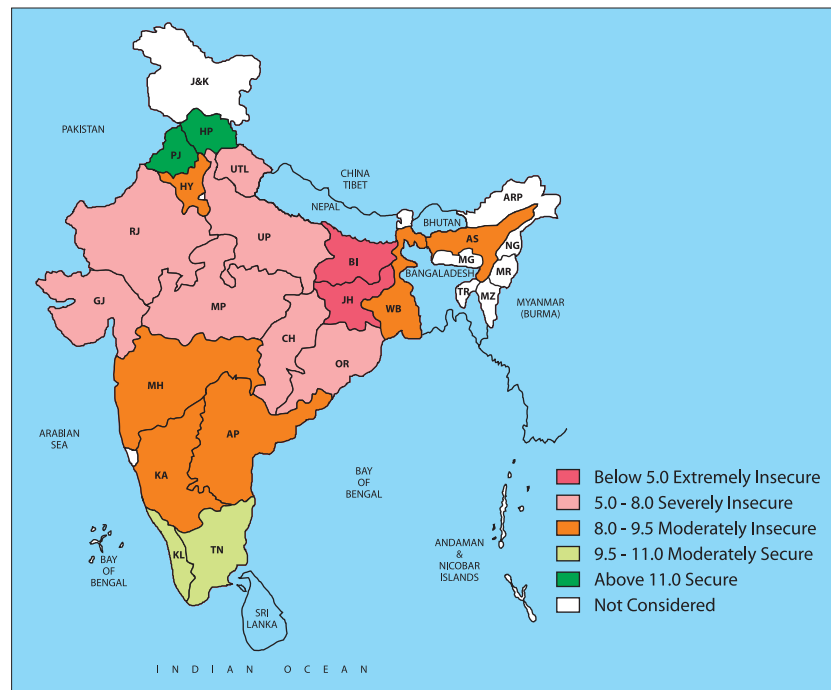
The geography of food insecurity. Mapping food insecurity is an important way of targeting areas

TABLE 1.
Geographic distribution of the rural poor (in millions).

Region (# countries) rural	Total population	Total rural population	Rural population on favored lands	Rural population on marginal lands	Rural poor on favored lands	Rural poor on marginal lands	Average rural poverty %
Sub-Saharan Africa (40)	530	375	101	274	65	175	64
Asia (20)	2,840	2,044	755	1,289	219	374	29
Central and South America (26)	430	117	40	77	24	47	61
West Asia and North Africa (40)	345	156	37	119	11	35	29
Total (106)	4,145	2,692	933	1,759	319	631	36

Source: Scherr 1999b, based on Nelson et al. 1997, table 2.4.

FIGURE 5.
Food insecurity in India.



Source: Food insecurity Atlas for Rural India, MSSRF-WFP 2001.

for action. An example for India is shown in figure 5. The index calculated by state is composed of five indicators for food availability and production, eight indicators for access to food and six indicators for food utilization.

The geography of malnutrition. An estimated 800 million people—one-sixth of the developing world's population—do not have access to sufficient food to lead healthy, productive lives. Around 280 million of these food-insecure people live in South Asia, 240 million in East Asia, 180 million in sub-Saharan Africa, and the rest in Latin America, the Middle East and North Africa. In the period from 1995 to 1997, 18 percent of the total population of the developing world was undernourished. Although progress is being made in tackling food insecurity, it is slow. In sub-Saharan Africa the number of food-insecure people has doubled since 1969–1971. According to recent FAO projections, the World Food

Summit goal of halving the number of food-insecure people from 800 million in 1995 to 400 million by 2015 will not be achieved until 2030 (Pinstrup-Andersen et al. 1999).

In 2000, 182 million preschool children—33 percent of all children under five in the developing world—were stunted or chronically undernourished; 27 percent were underweight. While the percentages appear to be dropping in Asia, they are escalating in Africa. Fourteen million children, most of them in developing countries, die every year from hunger-related disease—a number equivalent to three jumbo jets crashing every hour, every day of the year. Nearly half of all children living in the warm, semiarid tropics and subtropics are malnourished, as are more than one-third in the warm subhumid and humid tropics. A quarter of the children in the cool tropics and subtropics with summer rainfall suffer from malnutrition, while less than one-fifth do

likewise in the warm/cool humid subtropics and the cool subtropics with winter rainfall. Globally, 59 percent of all malnourished children in the developing world reside in the warm tropics, 27 percent in the warm subtropics, and 15 percent in the cool tropics and subtropics.

Relation between Food Security and Land and Water Degradation

Even though land and water degradation is often visible and is reported daily in the press, translation of this phenomenon into consequences for food security is difficult conceptually and in practice. The relation between degradation and food security is of enormous complexity due to the interactions between land, water, population, wealth and health and the rapid changes therein.

As many as 1.8 billion people live in areas with some noticeable land and water degradation, which reduces the quality of livelihoods and household food security. There is a pressing need for better information at local, national and global scales on these relationships. Nonetheless, it appears that areas with the greatest potential for land and water degradation—those with highly weathered soils, inadequate or excess rainfall and high temperatures—do correspond closely with areas of highest rural poverty and malnutrition.

It is logical to assume that land and water resources that are poor, or rapidly degrading, contribute to poverty and food insecurity. There are strong indications that the consequences of degradation for food security at the household level already affect many people significantly (e.g., Bridges et al. 2001; Scherr 2001).

Land and water degradation may impact food security by reducing household consumption, national food supplies, economic growth and natural capital.

Reduced Consumption of Rural Households

Land and water degradation affects rural household consumption by:

- Reducing subsistence food supplies.
- Reducing food purchases due to higher food prices.
- Reducing household incomes, by increased need for purchased farm inputs, increased share of food purchased and increased food prices.
- Reducing agricultural employment.
- Negative health effects due to reduced water quality or food consumption.
- Reducing the supply of water for domestic use as well as irrigation.
- Increasing difficulty of access to water.

In most developing countries, the rural poor depend on agriculture more than the rural affluent. Because poor farmers have limited access to external or industrial agricultural inputs, “natural capital”—the inherent productivity of their natural resources base including land and water is of particular importance to their livelihood security. The term “ecological poverty” has recently come into use to describe the type of widespread poverty that arises from degradation or loss of such natural capital. But ecological poverty not only leads to poverty but also results from it. When poor people have trouble securing food because of insufficient agricultural production or income, they may become even more dependent on “mining” land and water resources.

In areas of strong water competition, water tends to be reallocated to those who can pay or secure control over more. In such situations, it is the poor who are likely to lose access. In situations where water resources are being developed, it is the wealthier segments of society that are able to capture the benefits of the resource. Clearly, a poverty focus—with special attention on access rights to water—is required to assist the poor gain and maintain the use of water for food security.

Econometric evidence from China indicates that land and water degradation has a much greater effect on poor and densely populated districts than on other areas (Rozelle et al. 1997).

Reducing Global and National Food Supplies

While land and water degradation is clearly extensive, accurate global estimates of the productivity impacts do not exist. Very rough estimates, based on GLASOD biophysical data, suggest that globally the cumulative productivity losses from 1945 to 1990 were 11–13 percent for cropland and 4–9 percent for pasture. These cumulative cropland productivity losses are 45–365 percent higher in Africa, Asia and Latin America than in Europe and North America (although they are similar for pastureland). Degradation was light in most of Asia, but was serious in South Asia and montane Southeast Asia. For Africa, existing data suggest widespread loss of productive potential, due to intensive use of soil types that are highly sensitive to erosion and nutrient depletion, or are inherently low in nutrients and organic matter. Studies in Central America show high production losses due to erosion (Scherr 1999b).

Reducing Economic Growth

Degradation may reduce economic growth by:

- Economic multiplier effects of reduced farm household expenditures and agriculture-related industries.
- Higher food prices.
- Increased out-migration from degraded or water-scarce areas, thereby depressing urban wages.

Regional and national studies have produced a wide range of estimates of the magnitude of economic losses from soil degradation in the developing world, reported as a proportion of the agricultural gross domestic product (AGDP). Most are calculated in terms of the financial value of lost crop yields or the cost of purchasing fertilizer to replace nutrients lost through erosion or depletion. These estimates are quite high: 1–5 percent per annum in a majority of studies of soil erosion, and over 5 percent per annum in half of the studies of nutrient depletion. Calculating the discounted future stream of losses from soil degradation raises the cost to a figure equivalent to 35–44 percent of the AGDP in several studies in Ethiopia and Java. Several more sophisticated economic studies at the subnational scale in Rwanda and Mexico and at the national scales in Ghana and Nicaragua show the major economic impacts of soil degradation on farm incomes and—due to large multiplier effects—on overall economic growth (Scherr 1999a). In Latin America, high soil-nutrient depletion rates have been estimated in most cropping systems (Wood et al. 2000, table 20). The effects on yield have been masked by higher input use that increased farm production costs significantly and reduced farm income.

Reducing Natural Capital

Degradation directly reduces natural capital, causing:

- Damage to natural environments important for local ecosystem stability and agricultural production (e.g., wetlands).
- Increased risks of natural disasters (flooding and droughts).
- Reduced long-term capacity to supply food needs through domestic production due to reduced land area for production and reduced productivity.
- Damage to wild aquatic resources (fish, and aquatic animals such as frogs, snails and crabs, and aquatic plants such as lotus or reeds). These resources can be

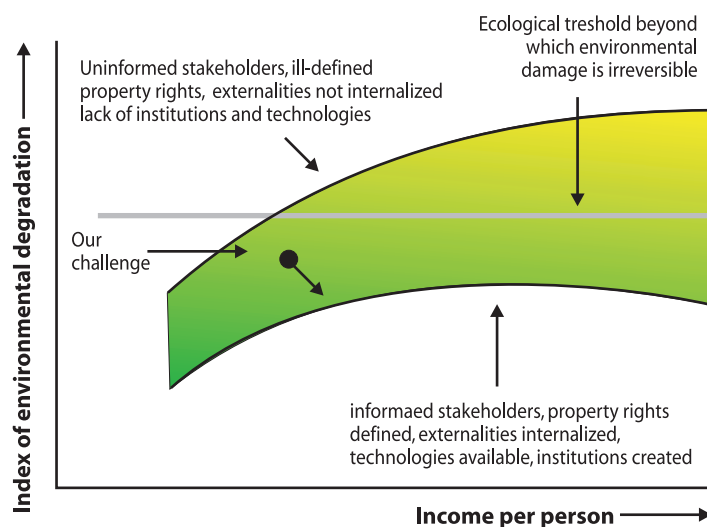
highly significant to the nutrition and income of rural communities, particularly for landless people.

Public Awareness

The ultimate driving factors of water and land degradation are (1) population growth, (2) growth in incomes and globalization, resulting in increased consumer demand for food, fiber, water and other resource-based products delinked from resource-carrying capacity, (3) urbanization, and (4) climatic change. These have a great momentum and are influenced by many factors themselves. More proximate variables of degradation are discussed in the next section, and suggestions are given in the subsequent section on how to modify them. Yet, the degree of public awareness on natural resources is also of crucial importance.

FIGURE 6.

The range of levels of environmental damage in relation to income, and the direction of development this report promotes (labeled “our challenge”) to minimize environmental degradation (after ADB 1997a, 214 and IBSRAM 1999).



Lomborg (2001) expresses optimism that societies will become aware and concerned about degradation of the natural environment, and that with rising incomes they will find ways to halt and reverse degradation. Some interesting examples from Europe and North America are provided. We consider this view overly optimistic for many developing countries. If a lack of “green” concerns is prevalent in a society, people are less willing to invest in environmental concerns. And if equity within society is not achieved, many people remain at a low income level even though the national average rises. If land and water resources are exploited beyond their threshold of resilience,* due to high population density or ecological fragility, the system fails rather suddenly. When this happens, in a short period land is lost for agriculture, water is no longer productive, national food security is reduced, and the option for income generation through agriculture disappears. These two contrasting possible outcomes are depicted in figure 6.

To reverse the trend from increasing environmental damage and degradation towards rehabilitation and improved livelihoods, as depicted in figure 6, governments and other stakeholders have to generate more public awareness and create options for environmentally friendly actions. Research organizations and enterprises encouraged by donors can facilitate the change by making investments technically more effective (“more crop per drop”), cheaper and more accessible. Public, civic and private investment to improve land and water management should be targeted closely on interventions that will reduce food insecurity. Governments can create an enabling environment to encompass policies and institutions that allow local people to participate in landscape- and watershed-scale planning processes; providing strong and equitable governance; securing the resource rights of food-insecure people; and providing mechanisms to value land and water quality in ways that inspire users and investors to conserve and improve them.

Land and Water Degradation and Food Insecurity: Processes and Management

Integrating Basin, Landscape and Farm-Level Assessment

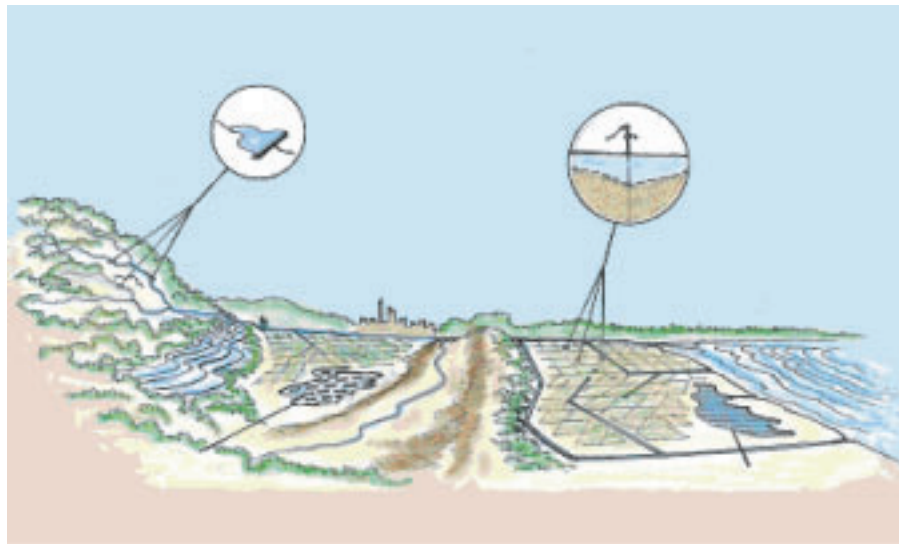
Understanding land and water degradation processes begins with an assessment at the basin scale. Rather than discussing the problems by continent or by biophysical process, we analyze situations in four broad geographical zones that constitute the basin, following the flow of water, in: “headwaters (upper watersheds),” “plains,” “cities” and “coastal areas.” Areas

within these zones but in different countries have similar degradation processes and underlying causes. Figure 7 is a graphical representation of the zones. These zones are interconnected and, therefore, should not be considered in isolation:

- Flow of freshwater through the zones, generally to the sea. Water flow and quality in the headwaters, influenced by vegetative cover and soil conditions, affect supply and quality downstream.

FIGURE 7.

An illustration of the zones: “headwaters” on the left, descending to “plains,” “cities” and “coastal areas.”



Source: Molden et al. 2002.

- Movement of plant nutrients,* generally from the headwaters and plains to the cities (as food) and the sea (as pollutants and sediment). Since there are no mechanisms to ensure recycling to the place of origin, this process contributes strongly to “nutrient depletion” in marginal areas in headwaters and plains, and to pollution in cities and peri-urban areas.
- Movement of food from rural areas to cities, from exporting regions to importing ones, and between basin and outside or international regions. The driving force is generally the difference in cost of production (plus transport) between the locations and produce quality. Food trade may also affect water consumption, if the water use efficiency is higher at the export site (current major food exporters, USA, Brazil and France have wetter climates than the major importers, China and African countries).
- Interconnections through infrastructure: roads, channels, housing, dams, airports, recreational facilities. These connections can have positive effects by making key inputs available and at lower prices (e.g., fertilizer), by giving farmers more options for increasing income and hence relieving the pressure on land (e.g., high-value vegetables and livestock products, even forest and tree products), and by facilitating more commuting and nonfarm activities). Yet, infrastructure is often laid out on good agricultural land, reducing the area of land available for food production, and its construction often accelerates land degradation. Roads, and even footpaths, are important contributors to erosion/ sedimentation.
- Movement of people, through permanent or temporary migration from degraded to less degraded but fragile agricultural regions or to cities.

Historically, these linkages have often served primarily the wealthier individuals of a community, particularly in urban conglomerates. By using resources from a large, noncontiguous area to produce food and the many other items they consume, they produce a large “ecological footprint.” Increasingly, however, it has been realized that new patterns of inter- and intra-basin connections are needed, which also ensure that food security needs and ecosystem services provided throughout the basin are protected.

Diverse configurations. While the basic basin structure is universal, patterns of land use vary greatly. In many parts of tropical Asia, historically, headwaters were left in forest or forest-abundant mosaics, and most agricultural production came from vast, intensively cultivated plains. In tropical Latin America, most crop production was in coastal areas (bananas) or in the headwaters (coffee, maize), while the plains were utilized mainly for extensive livestock production. Some highland plateaus, such as Mexico, have features of both plains and headwaters. Moreover, land-use systems reflect land quality, population density and market access, such that very different development pathways may be found, with associated patterns of degradation. Overall, irrigated lands account for about 7.5 percent of arable lands in developing countries, mostly in the plains. About 23 percent of arable lands is of the high-quality rain-fed type, and 35 percent of the rural population live here. These lands include both ecologically favored lands in the plains and some headwater areas, such as in parts of the East African Highlands. The other 69 percent of land is “marginal” land, where 65 percent of the population live. Most of the lands are settled, densely populated areas. Lands with lightly populated areas are either frontier zones or quite marginal (high altitude or dry semiarid climate) (Scherr 1999b).

Agricultural intensification per unit area of land use has the positive effect on global food security of increasing food supplies, and lowering the unit price of production, enabling even lower food prices than would arise from area expansion, an effect that improves household food security widely. However, if management is not adequate and inputs are unbalanced, then intensification contributes significantly to further degradation.

Headwaters (Upper Watersheds)

Driving factors of degradation. It is important to distinguish headwater areas that are sparsely populated (often largely forested) from those where human settlements over several generations, even millennia, have resulted in fairly intensive permanent cultivation.

In sparsely populated areas, degradation often starts with shifting cultivation (slash-and-burn), and in a few cases as logging operations. Over the last 50 years, the number of people has increased due to migration and relocation, and to the absence of effective laws or control measures. There is often insufficient intensification due to lack of appropriate and profitable technologies, and suitable markets. Farmers have to expand their crop area to meet their financial commitments and to satisfy the growing demand for food. Moreover, the legal status of many producers is irregular, as the land they cultivate and the water they seek have been claimed by the state for forest or conservation use, thus creating insecurity (discouraging land-improving investment); and there are no extension or credit services.

In the more populated headwaters, a major driver of degradation is that yields are not growing at a rate commensurate with population growth and increasing food needs. Riparian and other land-protecting natural vegetation may be removed to provide land; intensive crops with

several stages of crop and livestock integration replace extensive grazing systems. Many settled upland areas have large areas with tree crops, which are potentially less degrading, but only if they are managed well. Water rights are often restricted to protect supplies for more powerful downstream users. Government ownership of forests and tree resources, and restrictions on commercial use, discourage farmers from planting trees or protecting remnant forests.

Interestingly, there are also situations (the Mediterranean, the Philippines) where a reduction of the number of farmers leads to degradation, namely when young farmers move to urban areas and the reduced labor pool makes maintenance of structures (terraces, irrigation channels) uneconomical.

Analyses of the relationship between degradation and population in the Machakos district of Kenya suggested that a minimum population density is required for development to take off and that, if the number is too low, investments do not pay off and resource degradation continues. But access to roads and markets is also important, as well as suitable technology and investment options (Templeton and Scherr 1999). Simply having more people is not enough, and this leads all too easily to more erosion and declining per capita incomes, as seen in many other parts of the East African Highlands.

Farmers in headwater areas are often erroneously accused of causing land and water degradation. In many parts of the world, mining operations, infrastructure construction and natural geological processes are together the most important sources of sedimentation and pollution.

Land and water degradation processes. The most important processes contributing to degradation in this zone are erosion,* nutrient depletion,* water pollution,* devegetation* and a less regular stream flow.*

Erosion* leads to the displacement of both soil and the plant nutrients contained in it. Displaced soil is deposited downstream in fields, in water channels, reservoirs, or is transported along the river all the way to the sea. Unchecked, erosion continues until only bare rock and wasteland remain. While erosion is a natural process, human activities, particularly farming and the building of roads, paths and settlements, accelerate the process ten to hundredfold. High densities of animals on upper catchment grazing lands can also contribute significantly to erosion, particularly when the density exceeds the carrying capacity of the catchments. Appropriate conservation measures and management practices and careful location of roads and bridges can reduce erosion almost completely.

Water pollution* in headwaters is mainly due to erosion, and in some cases, to heavy metals from mineral mining and cities near streams and rivers. Pesticide levels in the water may be high near intensively cultivated crops. The watering of ruminant livestock at streams may also contribute to pollution, especially when the access of livestock to water resources is severely limited.

Problems with less regular stream flow include increased frequency of flooding in situ and downstream, and longer periods with minimal flow (base flow) due to the reduced water-retention capacity of the catchment. Also the total quantity of water may change due to land-use changes and degradation, as these processes affect the balance between evapotranspiration, infiltration and runoff.

Depletion of soil nutrients and reduction in soil organic matter* are common degradation processes in the lower parts of headwaters. This occurs because the required inputs are too costly (due to poor infrastructure and weak marketing institutions), proposed technologies are inappropriate, many farmers do not have resources to invest, or because incentives are

lacking. These result in lower yields, reduced yield stability and reduced input-use efficiency. In West Africa, application of manure with inorganic fertilizers is used as a strategy to combat soil nutrient and depletion of organic matter.

The type and location of vegetative cover constitute an important factor in determining the erosive impact of rainfall on soils, the path and rate of flow of water through the watershed, the sediment load in waterways, and the mix of freshwater species. Natural or planted vegetation around crop fields and pastures can limit the downstream movement of eroded soil and agricultural pollutants. Clearing of trees, bushes and perennial grasses around waterways, in steep areas and in and around crop fields, is thus a prominent cause of degradation, as is overgrazing of pastures, rangelands or forest floor vegetation.

*Degradation hotspots.** Much land and water degradation occurs in the foothills of the Himalayas, sloping areas in southern China and Southeast Asia, the East African Highlands, subhumid Central American hillsides and semiarid Andean valleys (Scherr and Yadav 1996). This is caused by the nature of the soils, the sloping landscapes, the rainfall regime, and land use. In vast geographic areas, all of the topsoil has been washed away. In others, the productive potential of the lands has been degraded significantly.

Effects on food security. Land and water degradation in headwaters can reduce household food security seriously, through reduced income and food production. This is a two-way process: a less-secure food production system often leads to more degrading farming practices, or the so-called “downward spiral.” Due to generally lower yields and higher transport costs, headwaters do not contribute much to global food security; however, they may play a very important role in national urban food supplies, and rural nonfarm populations.

Plains (Lowland Plains)

Driving factors of degradation. It is important to distinguish between different types of production systems in the lowland plains: intensive systems in irrigated and high-quality lands; low-productivity cropping systems in very dry or very wet areas; and extensive livestock systems. The principal driving factor of degradation in irrigated and intensive rain-fed agriculture is intensification, through increased and often inappropriate application of fertilizers, water and pesticides. Overuse or underuse of water, fertilizers and pesticides cause these problems. Intensification requires extra water, either from surface irrigation or from groundwater, and overuse or misappropriation leads to problems. Intensive livestock production produces high levels of potentially polluting wastes. Insufficient knowledge of the consequences of farm-, district-, and national-level decisions, and lack of incentives to use natural resources more judiciously, are behind these management practices. However, in some other cases, intensification is forcing a closer integration of crops and livestock, causing the farmers to become more aware of the need to manage their natural resources. Hence, in areas where the population density is high and there is much pressure on land, farmers are more likely to keep livestock as well as growing crops (Tarawali et al. 2001).

One of the difficulties in attempts to arrest agricultural pollution is that farmers see little benefit from changing their practices. This is often because of inappropriate policies, including underpriced water and fertilizer, and pesticide subsidies. A second difficulty is the dispersed nature of nonpoint source pollution—substantial agricultural pollution is the result of the actions by several farmers, and the entry point into the hydrologic systems is dispersed widely. This poses severe technical monitoring problems. Governments often control irrigation systems,

which suffer from poor design or management, constraining farmers to adopt different practices.

In low-intensity dryland and humid cropping systems, annual crop yields tend to be low. Degradation stems from attempts to intensify the use of these systems without sufficient investments taking place, inter alia land and water management (irrigation, water harvesting, supplementary irrigation, drainage and nutrient enrichment).

Land and water degradation processes.

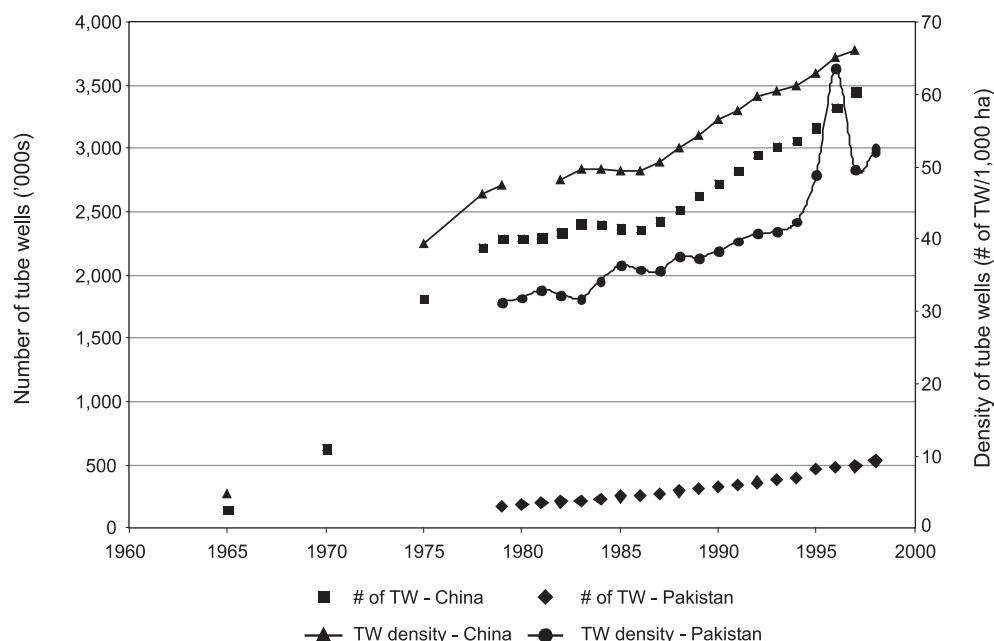
From the perspective of food security, the most important forms of land and water degradation are groundwater depletion,* salinization,* nutrient depletion,* water pollution,* devegetation,* and management circumstances.

While groundwater use in addition to surface water or rain is very effective for smallholders, there is only a limited amount of groundwater, and generally it is replenished slowly. The number of farmers using groundwater has increased significantly (figure 8) but pumping is

regulated rarely, so that the natural resource becomes exhausted and degraded, and pumping becomes more and more difficult (box 2).

Groundwater is heavily exploited by agriculture for several reasons (Shah et al. 2001). It is accessible to many; it can provide cheap, convenient, individual supplies; it is generally less capital-intensive to develop, and does not depend upon mega-water projects. And compared to large surface systems, whose design is driven by topography and hydraulics, groundwater development is often much more amenable to poverty-targeting. Yet, when muscle-driven traditional water lifts went out of business in South Asia with the advent of tube wells, it was the poor who were hit the hardest: new siting and licensing policies reinforced the rights of the early tube-well owners and excluded the latecomers, who typically are the poorest. Where groundwater levels drop to uneconomical levels, it will again be the poor who go out of business first.

FIGURE 8.
Groundwater development in China and Pakistan: Number and density of tube wells.

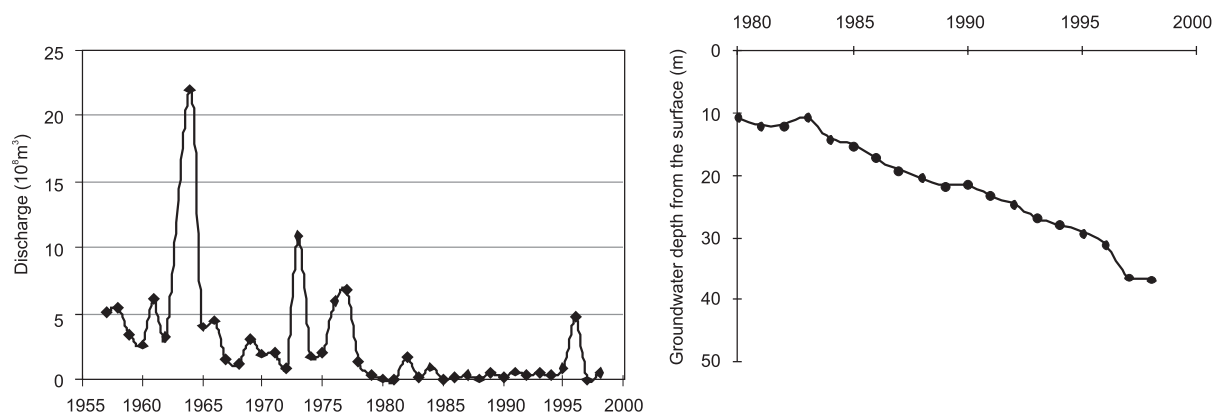


Source: Molden and Rijsberman 2001.

Box 2. River and Groundwater Depletion in the North China Plains.

The Fuyang river basin (FRB), a subbasin of Haihe Southern basin in Hebei Province of North China, drains an area of 22,814 km², receiving a mean annual precipitation of 569 mm. It is heavily equipped with water infrastructure, consisting of 3 large, 11 medium and 212 small reservoirs; 75% of water is allocated to agricultural use, 15% for industry and 10% for domestic use.

Up to the 1960s, the Fuyang river was an important shipping channel for Hebei Province. In contrast, from the 1990s onwards, the river had over 300 dry days annually. The outflows from the basin dramatically decreased from the late 1970s to less than 100 million cubic meters with no outflow in 1997. The graph on the left shows the declining discharge of the Fuyan measured at the Aixinzhuang Hydrology Station. The graph on the right shows the groundwater level of a typical well.



Water managers of Fuyang have allowed cities and industries first priority on reservoir water, and have supported farmers in their efforts to tap groundwater. In Fuyang, groundwater accounts for 80% of supply. Groundwater overdraft led to a dramatic drop of groundwater levels, especially in the last two decades. The groundwater table dropped at a rate of 0.68 m per year for the county located upstream and at a rate exceeding 1 m per year for middle and downstream counties. There is no institutional mechanism for dealing with this groundwater overdraft problem.

In the Fuyang basin, people are alarmed at the levels of pollution in the water system. Dilution no longer works, as flows are too small to carry out excess pollutants. Industries continue to discharge polluted effluents. Salinity levels are also rising from agricultural practices. People are concerned, but it is clear that they do not have the necessary setup to adequately deal with the problem. In FRB, agricultural productivity levels are quite high. But within the Fuyang basin, the amount of water limits the amount of production in the basin. They have met a stage of absolute physical water scarcity.

At present, agriculture supports a dense population that is, in general, able to meet basic livelihood requirements. But there will be a day when pumping rates will render water and agriculture unaffordable. The food and livelihood security of millions is at risk.

Groundwater depletion. Tube wells have arguably been the most significant innovation in irrigation in the last 50 years. The number of tube wells has risen dramatically in many of the major grain-producing areas (figure 8), allowing many farmers to intensify and stabilize agriculture on their land. But when groundwater withdrawals are higher than recharge, water tables drop. In many of the most pump-intensive areas of India and China, water tables are falling at rates of 1–3 m per year, or more. Groundwater is heavily exploited for agriculture because it is often accessible to many people and it represents a relatively cheap, convenient and individual water supply. Moreover, groundwater is generally less capital-intensive to develop than surface water. Tapping and distribution of groundwater do not necessarily involve development of a mega-water infrastructure.

We only have rough estimates of the contribution of groundwater irrigation to agriculture, and of the amount of unsustainable groundwater use. Postel (1999) estimated that the annual overdraft is around 200 km³, the equivalent of 3.5 years of water released from Egypt's High Aswan Dam. Even if this is a gross overestimate, there is clearly a problem. The national food security of India, Pakistan and China will be affected significantly by the way this groundwater problem is dealt with. Groundwater recharge is one solution, but it is not easy, and in some areas there is no water remaining to recharge. An alternative is to increase water productivity to achieve the same production but with less water.

River depletion and dessication. With intensive land and water use, primarily for irrigation withdrawal and consumption of water, especially by industry and for domestic use in growing urban centers, rivers are being depleted. Upstream development in the Yellow river, for example, leaves little river water for the users in the downstream plains. Increasing use upstream

of the Aral Sea basins has led to the drying up of the Aral Sea itself. River depletion leads to intensified competition, salinization and pollution. Food security is at risk for those people situated in downstream areas of the basin. And food security is also at risk for those living in upstream regions who do not have access to sufficient water for agriculture because water in rivers is being depleted further upstream. This is a predictable problem and it is advisable to solve it now than after the problem has intensified (Falkenmark 2001).

Salinization. Salinization is the accumulation of salt in the upper soil layers to the extent that crops can no longer produce good yields. Perhaps the most famous case of salinization was in ancient Mesopotamia where soil salinity due to irrigation was responsible for the fall of ancient civilizations (Postel 1999). Salinization of land is particularly prevalent in areas of high water tables with poor lateral drainage, with high evaporation rates and no opportunity for leaching excess salts, and sometimes with pumping of salty groundwater. Increased withdrawals for irrigation, combined with limited drainage, leads to salt buildup in river basins. Salts are accumulating in the Amu and Syr Darya, the Indus and the Nile rivers (Smedema 2000). Salinization can also occur in rain-fed land. Sodicity is a particular form of salinization.

Nutrient depletion. Most soils contain a stock of nutrients equal to 5–50 times the annual uptake. In sustainable agriculture, nutrients are resupplied in chemical or organic fertilizer at a rate commensurate with their removal or otherwise rendered unavailable for crop uptake. If this is not the case, nutrient depletion renders the soil infertile with time, and agriculture becomes marginal. Nutrient depletion is accompanied by a reduction in soil organic matter,* 40 percent of which is carbon. This form of degradation contributes to CO₂ emission and climate change.

Water pollution. Water pollution* is predominant in areas where agriculture has been intensified. Pollution from nonpoint agricultural sources results mostly from the leaching of agricultural chemicals or naturally occurring but harmful constituents from the soil. Pesticides in surface water are generally a more urgent problem. Pollution is particularly damaging when downstream water or aquifer water is a drinking water source. Pollution is harmful to many important ecosystems, and damages fisheries.

*Devegetation.** Pressure to intensify agriculture in the lowland plains has often led farmers to clear natural vegetation throughout the farm, including remnant forests, traditionally planted field hedgerows and farm boundary trees, and riparian vegetation, in order to expand planted area and more easily maneuver machinery. Such devegetation contributes to sediment and pollutant flow downstream, acceleration of runoff and loss of habitat.

Wind erosion. Wind erosion refers to displacement of soil particles by strong winds, particularly in dry climates. It has on-site consequences similar to water erosion, but the sedimentation process is more erratic. On rangelands, removal of vegetative cover makes the soils more vulnerable to wind erosion.

Hotspots. Hotspots of groundwater depletion are common in significant areas of the Indian subcontinent and Northeast China. Hotspots of nutrient depletion include much of Africa (Drechsel et al. 2001), rain-fed areas of West, South and Southeast Asia, and rain-fed areas in Central America. Wind erosion is severe in some countries, particularly in China and Africa, and Huang (2000) estimates that globally it affects an area half as large as that for water erosion.

With increases in irrigated areas, there have been increases in salinization in many areas of the world including the Indus basin in India and

Pakistan, the Central Asian republics, and China. Arid areas are particularly sensitive to salinization problems, such as the Near East, where 29 percent of the irrigated areas in the eight countries is reported as having salinization problems, varying from 3.5 percent in Jordan to over 85 percent in Kuwait.

Consequences for food security. The Plains are the geographic zone where most food and feed production takes place in large parts of the world, particularly in Asia, North and South America and Australia. Irrigated systems are very important from the point of view of food production ("food baskets"), even though 60–70 percent of all food is produced in rain-fed systems. Degradation of land and reduced availability of water in the plains lower the ultimate potential of global food production.

National food security for countries such as India, Pakistan and China will be affected significantly if the current rates of groundwater consumption are not reduced. Salinization is a threat to national food security in countries where it is prevalent, and a threat to the livelihoods and households of the farmers affected.

The groups of landless people in many countries are growing. This class does not benefit much from many types of agricultural intensification and, hence, becomes poorer and more food insecure. Deforestation and devegetation may deprive the poor of important food, fuel, medicines, fodder and other resources critical to their livelihoods.

New irrigation schemes may introduce malaria and other diseases, reducing food utilization. However, positive income effects can stimulate health promotion and keep them at bay. Water pollution reduces food security by limiting the amount of water that can be used by crops, and polluting aquatic food sources. Where polluted water is used for domestic uses, people's health is at risk. Water pollution is highly significant in reducing household food security in rural areas, and downstream, in cities.

Urban and Peri-Urban Areas

Driving factors of degradation. A major driving force of degradation is the intensive use of resources. As cities grow and inhabitants become more affluent, this driving force will become much stronger. This is because the consumption of food and water in these areas is much higher than in the other zones, and the capacity for natural restoration is much exceeded, or sometimes even destroyed (e.g., “dead” city canals).

Another form of degradation of the land from an agricultural perspective is the expansion of infrastructure (houses, roads, industrial areas, golf courses) to accommodate the growing number of people and their needs for transport and recreation. This process consumes annually about 0.5 percent per year of prime land. Higher rates are observed in some locations.

Soil and water pollution in these urban areas is a consequence not only of human and industrial wastes but also of the importation of large quantities of food and animal feed (Faerge et al. 2001), whose waste is often disposed of improperly. The recycling of water and waste is still uncommon and needs encouragement from the point of view of plant nutrition, and this lack of treatment also presents health hazards. Avoiding such health issues requires the establishment of clear standards, and proper monitoring of produce quality. Monitoring techniques and indicators to assess land and water quality are fairly well developed.

Degradation processes. Land and water degradation in urban and peri-urban areas takes many forms: changes in hydrology, subsidence, water and soil pollution and nonagricultural use of land and water.

Runoff from rainfall in cities is much more rapid, so that the hydrological characteristics of urban areas are different. This can lead to temporary flooding of infrastructure and

buildings; and mass movement of soil from steep slopes can destroy much property. It also leads to reduced recharging of groundwater. As groundwater under cities is depleted by withdrawal for industrial and domestic use, subsidence may occur, causing extensive damage to roads and buildings, and cracked sewers that add to health problems. Changes in sea levels due to climatic change may result in lower areas of cities becoming uninhabitable.

Moreover, many cities actively modify hydrological systems in order to develop more reliable water supplies (e.g., bringing in water from long distances away, and storing it in man-made reservoirs) or to protect urban areas from natural flooding, through dikes, etc. Engineering designs often disrupt natural patterns of water flow, with attendant threats to biodiversity dependent on freshwater.

As the recycling of plant nutrients in waste food material back to soils is limited, many nutrients end up in the urban environment and in rivers leading through them. Intensive poultry, pig, and seafood production enterprises close to mega-cities can result in large nutrient effluxes and pollution through organic wastes to both downstream cities and coastal areas. In addition, there are also significant direct and indirect negative health impacts (and hence reduced household food security) and environmental impacts.

Approximately 800 million people globally are engaged in urban agriculture, of whom 200 million are farmers producing for sale in the market. In eight African and three Asian countries, 33–80 percent of urban families are engaged in food, horticultural or livestock production. Contrary to popular belief, a high proportion of urban land is available for agriculture, although tenure in many of these spaces is highly uncertain. Overuse of nutrients, the opposite of depletion, occurs in peri-urban agriculture and often for high-value crops, as in horticulture and floriculture (Scherr 1999a).

The excess nutrients, often mixed with pesticides, pollute water and soil. Downstream areas of rivers near rapidly developing mega-cities are often heavily polluted (Drechsel and Kunze 2001).

Nonagricultural use of land and water is a complex issue in itself. Cities “consume” much land and water that otherwise form part of an agro-ecosystem and are withdrawn from agriculture. In general, these lands and water are used in other economic enterprises and provide an income larger than that from agriculture. The impact on global food security is small, although a significant fraction of highly productive land and water is consumed for this purpose. Whether the impact on household food security is positive depends on how income is distributed.

Degradation hotspots. Hotspots are the large and very large cities with little water in the form of rain or rivers, and with little facilities to handle waste and wastewater. These include most mega-cities in developing countries: Mumbai, Lagos, Dhaka, Sao Paulo, Karachi, Mexico City, Jakarta, Calcutta, Delhi, Manila, Buenos Aires, Cairo, Istanbul, Beijing, Rio de Janeiro, Hyderabad and Bangkok. Hotspots include probably all major urban conglomerations. In the peri-urban areas, concentrated livestock production poses particular problems of waste disposal, and water and land degradation. The strongest effects are in the water immediately downstream of and under the city, and in the land on which it is built and that which surrounds it.

Consequences for food security. At a national scale, the expansion of mega-cities will result in less land for agricultural enterprises and hence less food production. At the household scale, urban and peri-urban agriculture often provides good income, and increases household food security. Use of wastewater and compost on crops assists in the recycling of nutrients and stimulates income generation. However, the risk of contaminating edible food sources increases.

Dirty waterways in the city reduce the quality of livelihoods, particularly of those living in close proximity, namely the urban poor. As health risks increase, it is the poorer sectors of the economy that are most vulnerable and as a consequence food security is reduced.

Wastewater generated by cities is often discharged without primary treatment into rivers and therefore becomes a health hazard for those reliant on this water downstream. Natural fish production in rivers is reduced in rivers affected by pollution, particularly when chemicals from mining industries or factories are discharged into them. Due to the use of wastewater and the reliance on pesticides, production and consumption of vegetables in urban and peri-urban areas often become a health hazard, and hence reduce food security.

Coastal Areas

Driving factors of degradation. Some 39 percent of the world’s population live within 100 km of the coast. In Southeast Asia alone, 380 million persons live within 60 km of the coastline. This high density, supplemented in some areas by a significant tourist population, puts pressure on coastal and marine environments. Natural zones are being converted into zones that are not necessarily more productive in terms of food supply. Shoreline modification has altered sea currents and sediment delivery mechanisms. Artificial mechanisms for shoreline stabilization replace the natural buffering capacity of natural systems, such as mangroves and mudflats, to protect against storms. Climatic change can potentially have dramatic impacts on coastal areas through increased frequency and strengths of storms and by loss of fertile area by rising waters.

Coastal areas are at the receiving end of upstream land- and water-degradation processes—these zones receive the sediment loads and pollution transported by water from

upstream agriculture and cities. These areas must also absorb changes brought about by reduced river discharges and a modified discharge hydrograph brought about by upstream development. Large populations put pressure on coastal and marine environments.

Encroachment* occurs in fragile wetlands and in coastal areas.

Degradation processes. The main processes are seawater intrusion, dessication of rivers and pollution and sedimentation in coastal water. Unsustainable reclamation of wetlands is another form of degradation.

*Seawater intrusion.** Saline seawater moves inland into river systems or aquifer systems. The physical causes include lowering of aquifer levels, reducing the discharge of rivers, the rising sea level (1–2 mm per year) and prolonged droughts. Pumping of aquifers in excess of freshwater recharge lowers their levels and draws seawater further inland. The phenomenon is particularly dangerous in that it is extremely difficult to detect. Over a relatively short period of time, well water can turn from fresh, to brackish, to saline and destroy freshwater sources for agriculture or cities. The process can only be reversed by recharging additional freshwater.

On-site effects are salinization of freshwater sources resulting in degraded drinking and agricultural water quality (Shah et al. 2001). On the Saurashtra coast of the West Indian state of Gujarat, sustained overpumping by private farming communities during the 1960s and 1970s generated previously unseen prosperity, earning the coastal strip the sobriquet “Green Creeper.” But rapid seawater intrusion in coastal aquifers—which extended to an alarming 7 km inland in a decade—caused a rapid collapse in farm productivity, and hence in household food security.

Reduced agricultural activity because of seawater intrusion reduces agricultural activities

and thereby reduces a source of income for farmers within coastal areas. The problem of intrusion is widespread and is likely to increase because of growing water needs, increasing dependence on groundwater and the possible adverse impacts of climatic change.

River desiccation. Growth in the consumption of water, in particular by the agriculture sector, leads to drastically reduced or dried-up rivers in coastal areas. In dry regions, the irrigation process increases evapotranspiration* from land surfaces in order to produce crops. As a result, river discharges diminish. In many basins, such as the Colorado river, Egypt’s Nile, the Yellow river, and the Amu and Syr Darya, this phenomenon is well documented. River dessication is the result of upstream activities that are often based on decisions taken without considering environmental flows and downstream effects.

There are many effects of reduced river flow that lead to reduction of household food security and damage or destruction to ecosystems and the services they provide. Tropical coastal estuaries and lagoon systems are the second most productive aquatic system, after coral reefs (three times more productive than cultivated land, and their fishery production is correlated to river discharge (Yanez-Arancibia et al. 1985; Loneragan and Bunn 1999). Besides the natural systems, agricultural areas in coastal regions may suffer because of lack of water. In a chain reaction farmers once relying on surface water, may turn to pumping groundwater that, in turn, induces seawater intrusion. Reduced flows result in higher concentrations of pollution, which impact on human and ecosystem health. Livelihoods dependent on crop agriculture or fisheries are particularly at risk due to this phenomenon if yields are reduced or agricultural areas are retired. These different interactions call for an integrated approach of coastal systems (Day et al. 1997). In 1999, UNEP launched the concept of Integrated Coastal Area and River

Basin Management (ICARM) and provided a conceptual framework and planning guidelines. It is necessary to include coastal and marine functions in environmental flows, and one should consider not only river flows that maintain annual cycles but also flows that reset or maintain the coastal system on a geomorphological basis (exceptional floods).

Pollution and sedimentation from upstream areas. Deterioration of water quality includes inputs of excessive nutrients and organic matter to coastal waters (eutrophication) and toxic materials (heavy metals, oil, pesticides). Mangroves can be used as natural sinks to remove excess nutrients from wastewater before release to the sea (Twilley 1998). In addition to pollution, excessive sedimentation carried by rivers from upstream is a major source of damage to coral reefs, killing the living corals by covering them, thereby reducing the habitat and the associated fisheries. Sixty percent of coral reefs are at threat globally—80 percent is under severe threat in Asia (Bryant et al. 1998). This impacts severely on the generation of income, in particular for coastal communities dependent upon these natural resources.

Unsustainable conversion of coastal wetlands. Coastal wetlands (including mangroves, swamps, salt marshes and peatlands) are among the most species-rich natural habitats, and play an important role in coastal ecosystem functions. Half of the coastal wetlands are estimated to have been lost in the twentieth century, with land development for agriculture as the leading factor. Most attempts to utilize mangroves for aquaculture or agriculture have been unsuccessful. Such soils suffer from severe acidification problems that are difficult to manage, and the rapid oxidation of the iron pyrites on the acid sulfate soils leads to the formation of free sulfuric acid in the soil and

consequent soil sterility (Greenland et al. 1994). When converted to aquacultural farms, these lands are used for 5–10 years until they become sterile and cease to contribute to food security at any level.

Wetlands conversion. Wetlands (including swamps, marshes, lakes, rivers, estuaries and peatlands) are among the most species-rich natural habitats and play an important role in ecosystem functions.

Hotspots. Coastal area and delta degradation due to sedimentation and water pollution is prevalent particularly in Southeast and East Asia. The extent of seawater intrusion is not well known, but there are examples of its prevalence in coastal areas of Egypt, China, India and Turkey. More than 70,000 synthetic chemicals have been identified as being discharged into the ocean (Burke et al. 2001).

Impacts on food security. Fisheries in natural waters and aquaculture contribute significantly to the provision of food. In Asia for instance, the volume of fish products far outweighs any one of the four main terrestrial animal commodity groups—beef, sheep, pig and poultry meat. In fact, fish production in the developing world, totaling about 60 million tonnes, is close to the total of all the four animal commodities combined (about 70 million tonnes, ADB 1997b). More than one billion people around the world depend upon fish as their primary source of animal protein. Degradation has a negative effect on those who rely on fishing for their livelihood (catches decline, and fish become smaller and cheaper). Quick-profit aquaculture (e.g., widespread systems of shrimp farming) contributes to degradation by destroying mangrove forests and polluting the soil, leaving the owner of the soil (after this productive phase) without fertile land for further agricultural income.

Improving Land and Water Resources: Lessons Learned

Learn from Bright Spots

While the aggregate picture of land and water degradation is quite worrying, there are also many bright spots where either local adaptation or external intervention has stopped or even reversed degradation. We can learn important lessons from these experiences. Some examples from headwaters (upper watersheds) include conservation farming in the Philippines and Thailand, hillside conservation investment in East Africa (Rwanda, Kenya and Burundi), projects in Morocco, West Cameroon, and Fouta Djallon in Guinea. There is widespread adoption of specific technologies, including conservation tillage (Mexico, Central America, Brazil, Argentina, Chile, Uruguay and Paraguay), use of perennial crops (in the mountains of Himachal Pradesh, India and on hillsides of southern Mexico and Central America), multistoried gardens (in densely populated areas with volcanic soils in Indonesia and southern China), and perennial plantations in areas of low population density with fragile soils (Malaysia, India, southern Thailand and the Philippines) (Scherr and Yadav 1996).

Rehabilitation has occurred in parts of South America and China, where rain-fed agriculture with legumes, organic and chemical fertilizer, and no-tillage practices are well developed. Bright spots for salinization include the modern irrigation technology in Jordan, effective irrigation systems in Mexico and the expanding small-scale irrigation in semiarid areas of Africa and the Andes (Scherr and Yadav 1996). Bright spots for household food security include increased use of small-scale irrigation equipment for supplementary irrigation; this leads to higher and more stable income, and raises production and access to, and utilization of, food in several countries (e.g., Bangladesh, India).

Examples of successful projects can also be found in the report of Pretty and Hine (2001). Although the project did not focus on land degradation per se, it has examples of benefits to soils and water. In addition to the requirements for enabling environments, the authors emphasize the need for “social learning” as a key component for success and scaling out.

The Benefit of Integrated Analysis of Degradation Problems and Solutions

Integrated land and water management approaches provide a comprehensive framework for countries to manage land and water resources in a way that recognizes political and social factors as well as the need to protect the integrity and function of ecological systems. These approaches emphasize cross-sectoral and broad stakeholder participation in land- and water-management planning and implementation.

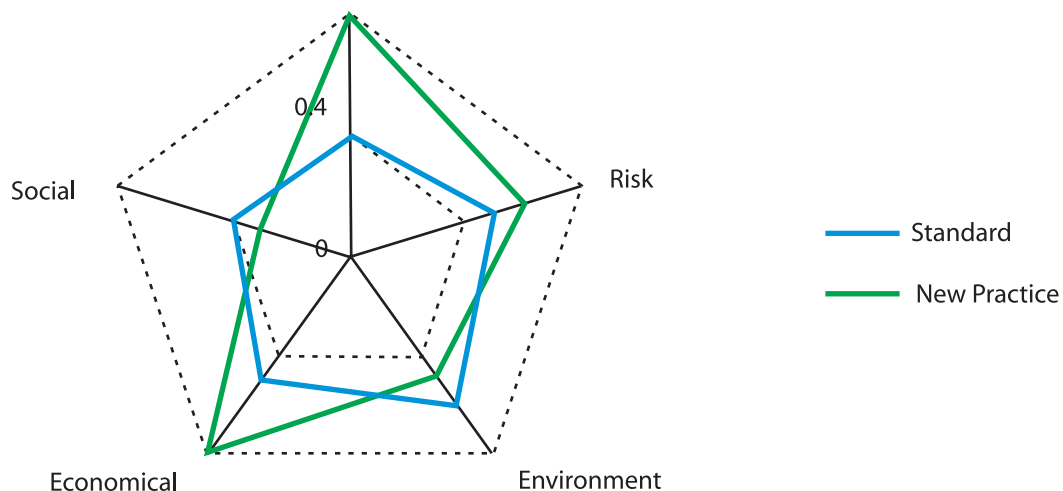
The need for a paradigm shift from a single-sector approach to an integrated land- and water-management approach is supported by the experience from both developed countries and developing countries. Although it often leads to short-term economic gains, the single-sector approach to land and water management can result in long-term environmental degradation because it fails to account for the complex linkages among various components of the ecosystem. The single-sector approach typically seeks to maximize the benefits of one sector such as irrigated agriculture without considering the impacts on other sectors. In addition, this approach tends to rely heavily on technical and engineering solutions, making little or no attempt to address related policy and institutional issues.

Development activities in the Senegal river valley highlight many of the unintended environmental and social impacts of the single-sector approach to land and water management. Two dams were constructed on the Senegal river in the 1970s to support intensive rice production, electricity generation and year-round navigation. Environmental and social considerations were not fully addressed in the design of the projects. As a result, the projects' initial economic success, in terms of rice production and electricity, has been overtaken by rising environmental and social costs. About 50 percent of the irrigation fields have been lost to soil salinization; dams and dykes have reduced traditional grazing lands from 80,000 hectares to 4,000 hectares; water pollution from pesticides and other agrochemicals is prevalent; and fish production in the river and estuary has dropped by 90 percent (Pirot et al. 2000).

Improved technologies and practices must satisfy, as far as possible, the requirements for the five dimensions of sustainable agriculture: increased productivity, reduced risk, increased resource protection, economic viability and social acceptability (Smyth and Dumanski 1993, who termed these dimensions "pillars of sustainability"). Coughlan and Lefroy (2001) showed how the benefits of a new technology (use of chicken manure in West African peri-urban agriculture) can be measured along these five pillars. If such results are expressed in a radar diagram (figure 9), an integrated picture is obtained, allowing a holistic comparison of old and new technologies. Such a multidimensional representation is also being used increasingly to characterize livelihoods at the village level (see <http://www.aplivelihoods.org/whatlivelihoodapproach.html>).

FIGURE 9.

A hypothetical example of two technologies that are compared along the five dimensions of sustainability. The "standard" technology represents cultivation of a traditional rice variety and the "new practice" refers to growing a new variety with higher and more stable yields, but also putting more strain on farmers' working hours and increasing water pollution.



Therefore, to set priorities for the introduction of new technologies, the following aspects should be considered in making decisions on whether and how much to invest in land- and water-resources protection or improvement:

- Relative importance of the problem from a food-security perspective (household consumption, food supplies, economic growth, long-term security).
- Resource damage and recovery functions—how resilient is the resource?
- Whether the investment makes economic sense (cost-benefit relations; relative returns to prevention versus rehabilitation; opportunity costs of investment).
- Land quality that must be protected to meet the food security needs of future generations.
- Expectations of the likelihood that farmers and communities will be able or willing to resolve the problems themselves within a reasonable time period.
- Extent to which it makes sense, from a social perspective, for users to convert natural capital (through “degradation”) to other types of capital.

Monitoring of the status of land and water and measuring the various ecosystem services provided by these natural resources is essential for the implementation of policies. It is also necessary for meaningful discussions on various trade-offs in the various services among the stakeholders. However, this is still a very difficult issue at the levels of concepts, sampling methods, actual measurement and interpretation.

The Need for Lower-Cost Technologies and Management Practices

With respect to land and water, past technological developments have focused primarily on ways to increase their use and output:

1. Higher crop yields and livestock head per unit of land and water (selection, breeding, biotechnology and resource management).
2. Replacement of human and animal labor by machines (e.g., tractors) allowing individuals to cultivate larger areas.
3. Increases in the volume of accessible irrigation and drinking water (e.g., reservoirs, diversion structures, pumps).
4. Replacement of human observations by the readings of instruments for more consistent management (e.g., soil probes that trigger irrigation when the soil is dry).
5. Refinement of management practices to produce the same output or more with less inputs and reduced risk (e.g., precision agriculture, drip irrigation, weather forecasts).

Much has been learned about the technical aspects of land and water conservation for low-income resource users, from a basin or landscape perspective. Technologies with the following characteristics are much more adoptable and acceptable:

- Low cost, particularly in terms of cash.
- Familiar components.
- Can be adopted incrementally (to allow for self-financing).

- Contribute demonstrably to increased yields or reduced costs within a 1–3 year period.

Thus, vegetative barriers have proven more adoptable and sustainable than structures, in many cases. But much lower-cost systems are still needed. A general plea can be made that more “best practices to manage land and water for food security” are to be identified, described, generalized and made widely available.

Farming systems based on ecological principles could do a better job in generating and recycling organic matter and plant nutrients, and in protecting natural resources, than many modern but unbalanced systems. This includes the use of tree-based land use on hillsides.

Finally, we have learned that land- and water-management systems must be planned together with farmers and the communities that share the basin or subcatchment, to ensure that high priority sites are treated and there is agreement on expected resource flows. In many environments, there is a need to encourage landscape “mosaics,” with careful placement of landscape “filters” and “corridors” for the flow of nutrients, water, etc., through the system (Van Noordwijk et al. 1998).

The Importance of Incentives for Investments in Land and Water Resources

With a few exceptions, people do not intend deliberately to degrade the natural resources they use, but their decisions to do so are guided by economic realities or lack of knowledge. Consequently, we focus on these realities and on providing knowledge. Policy interventions that seek to overcome environmental problems in agriculture need to be based on a proper understanding of why farmers’ practices lead to degradation of their environment. Why, for example, do farmers often seem to overgraze

rangeland, deplete soil nutrients and organic matter, and overuse irrigation water, pesticides and nitrogen, when these actions cause health problems and reduce future incomes for themselves, their children, and the communities in which they live? The answer lies with the incentives facing farmers. Farmers are not irrational. On the contrary, they maximize income and minimize risk in a dynamic context and often under harsh conditions and serious constraints. They degrade resources when there are good economic and social reasons for doing so, i.e., when the benefits they obtain exceed the perceived costs that they, as individuals, must bear.

The off-site economic impacts of degradation are likely to be quite significant, but in most cases they are still hard to quantify due to lack of biophysical data (Enters 1998). Yet, such externalities need to be internalized. Many externalities must be negotiated directly, and others can be influenced by changing prices, for example, through taxes on pollutants, removal of subsidies for water, etc. As long as such negative externalities are not internalized, it is unrealistic to expect land and water users to respond to downstream degradation problems.

There is a growing recognition that self-financing by smallholders and microcredit for smallholders can be very effective instruments for improving land and water management and for increasing household food security. Of crucial importance to facilitate these mechanisms is the creation of an enabling socioeconomic environment and legal framework. Improvement of these conditions, tailored to the specific needs of an area, can be very successful without major public funds. There is a clear role for the private sector in protecting resources that they are using, and in providing professional services.

There is a need for large-scale public investment, particularly in developing water and irrigation systems, and in other major land improvements that are beyond the capacity of local groups to finance or implement. For large

projects, maintenance should be carried out with local resources. Later we focus directly on issues of resource mobilization for combating land and water degradation and enhancing food security.

The Value of Participatory Planning and Implementation

Many of the problems of land and water degradation can be traced to weak or nonexistent institutions. Various types of institutions are required at the farm, community, regional and national levels. Learning lessons from successful institutional frameworks and institution building efforts related to land and water degradation should be given high priority. Basic approaches deal with different stakeholders and with learning to compromise. Tradeoff involves participatory development and research. Long-term involvement and commitment of the key stakeholder groups, including the private sector, are required. Institutional issues are most important but very complex. Although awareness is slowly emerging in this regard, the issues are overwhelming.

There may be a need for collective investments by user groups, such as establishing shelterbelts or drainage systems, when these are beyond the capacity of individual farmers. Groups can also help encourage and support one another to undertake investments on individual farms. Landcare programs in Australia and Southeast Asia have taken over much of the extension role through such groups, with only minimal public subsidies.

Organizations of local watershed users are developing in many parts of the world. Some are federating or organizing into cooperatives to take action in policy negotiations. Very successful examples are the Water Watch programs that have spread in Southeast Asia, the Andes and elsewhere.

Because of the unique conditions at every site and for every situation, technologies will always require local adaptation. On-farm research and extension approaches that facilitate adaptation processes by greatly increasing the role of local users have been very effective. Technologies must be developed with a clear understanding of the socioeconomic conditions of users, market conditions, roads and transport infrastructure, distribution systems, etc. Thus farmers in remote areas cannot depend mainly upon externally supplied inputs, but will need to work with local resources. Farmers operating in active markets cannot adopt practices whose returns on labor are lower than the local wage rate.

Awareness of the many technological options for land and water management, whose effectiveness has already been proven, is still quite limited. Adoption is also limited due to incomplete or even incorrect perceptions about the state and importance of natural resources among land and water users, and the public at large. Newspapers and television, environmental education at school, and “green activists” play important roles in awareness development.

The Critical Role of Enabling Public Policy

The creation of an enabling environment for smallholder farmers and planning agencies to adopt management practices that reduce land and water degradation and improve food security is crucial. It is important to create a legal framework to define what activities are allowed in a particular area, who is responsible for them and for the state of the resources, and who does the overseeing. Then the legal framework must be implemented effectively. Internationally accepted standards are needed on maximum contamination of soil and water that is used for different purposes (Hannam and Boer 2001).

Within the arena of law and politics, an important issue is to provide smallholders with secure tenure or long-term arrangements for land use, and water users with assured rights to this resource. The absence of such rights is an important constraint for farmers in mobilizing funds and investing them in their farms, improving livelihoods and reducing degradation. Assuring long-term rights to land and water is a necessary, if not always sufficient, action that is needed to halt degradation and assure poor people of a decent option to earn a living through agriculture.

Globalization

Globalization has had many significant impacts on the volume and destination of trade in food

and feed. While most food consumed is produced domestically, large volumes are traded internationally, and trade will likely increase significantly in the near future. This will have major impacts on the crops produced in different countries, on food and feed purchased, and on the water required for crop production and crop nutrients transported in the crops. The potential effects of globalization on land and water degradation and improvement constitute an important and complex issue. Moreover, the impacts arising from market distortions such as subsidies and trade barriers in a global market are also significant. The importance of the potential impacts from globalization cannot be overstated and is acknowledged; however, the sheer complexity of the issue precludes its inclusion in the present report and is deferred until future research efforts are conducted.

Priority Actions

Five priority actions are proposed for countries to enable them to simultaneously enhance food security and environmental security. These actions are:

1. Mainstreaming of integrated land- and water-management approaches.
2. Strengthening of the enabling environment.
3. Wider adoption of good management practices and environmentally sound technologies.
4. Expansion and acceleration of capacity-development activities.
5. Strengthening of partnerships at the local, national and international levels to provide a mechanism for a coordinated response to the issue of food and environmental security.

Mainstream Integrated Approaches to Land and Water Management

Countries need to mainstream integrated approaches to land and water management in their sustainable development programs, particularly in national and local development plans, agricultural plans and budgetary allocations.

A shift from the single-sector approach to integrated approaches offers several advantages. Integrated approaches provide a comprehensive framework for the management of a broad range of sectors by many stakeholders (resource owners, managers and users; and upstream users and downstream users). These stakeholders should participate in resource allocation and management decisions, taking into account ecological, economic and social factors. Such an approach minimizes conflicts over resource allocation and management. In addition, integrated approaches facilitate the application of technical and engineering solutions in association with needed policy and institutional reforms.

Integrated approaches to land and water management are not new. In fact, traditional or indigenous systems of natural resources management are based on an integrated approach to conservation and sustainable use of natural resources. In addition, several countries have established river-basin management programs as an attempt to utilize integrated approaches. Countries need to intensify efforts to identify and overcome barriers to the successful evolution of these systems to meet emerging challenges.

Strengthen the Enabling Environment for Integrated Land and Water Management

Integrated land- and water-management approaches can succeed in an environment with appropriate policies, regulations and institutional arrangements. Countries should, therefore, give priority to strengthening policies, regulations and institutions in ways that facilitate the wider adoption of integrated and cross-sectoral approaches to land and water management. Countries need to reform institutional arrangements for land and water management to facilitate cross-sectoral and multi-stakeholder

involvement in integrated management planning and implementation.

One of the major policy issues in agricultural development is security of both land tenure and water rights. Experience around the world indicates that resource users are less willing to make investments to protect the environment when they have no ownership or when access is restricted. In the absence of such security, they focus on maximizing short-term benefits, often to the detriment of the environment.

A second major policy issue in agricultural development is subsidies and pricing of inputs such as land, water, seeds and agrochemicals. There is ample evidence that underpricing of natural resources and subsidies for agricultural inputs can lead to overexploitation of natural resources and degradation of the environment.

Policies on tenure security, subsidies, pricing and other factors need to be developed in ways that promote equitable and reliable resource access, efficient resource use and environmental protection.

Adopt More Widespread Good Management Practices and Environmentally Sound Technologies

There are traditional and contemporary land- and water-management practices and technologies that can help improve food and environmental security. Countries need to provide the appropriate enabling environment, incentives and financial resources to promote the adoption of these practices and technologies as well as facilitating the development, dissemination and adoption of innovations to improve the productivity of land and water in an environmentally sound way.

Priority may be given to facilitating the development and wider adoption of good management practices and technologies such as low/zero tillage and farming systems that use drought-resistant or low water-consuming crop

varieties as well as more water-efficient irrigation systems. The development and adoption of management practices and technologies could be facilitated by collaboration among public and private international agricultural research centers, national research centers, conservation organizations, policymakers, local farmers and other resource users.

Expand and Accelerate Capacity Development

Countries may have the best information on the enabling environment and on resource-management practices and technologies, yet fail to achieve wider adoption of integrated land- and water-management approaches due to lack of skilled human resources to plan and implement programs. Therefore, countries need to expand and accelerate capacity development activities through in-country formal and informal educational programs, advanced overseas training, and staff exchanges among developing countries and between developed countries and developing countries.

Capacity-development programs should be tailored to the needs of specific stakeholder groups involved in a particular resource-management issue, bringing together the expertise and experience of local and international organizations. These programs can help, depending on the stakeholder groups targeted, to raise environmental awareness, improve technical skills and provide facilities and equipment to support integrated natural resources management activities.

Training priorities for four stakeholder groups may include the following:

- a. *National and local economic and development planners:* Formal training (in-service training, in-country and overseas courses, and staff exchange) on the sustainable management of

renewable natural resources, the economic valuation of natural resources, and the use of market-based instruments in natural-resources management.

- b. *Resource owners such as government entities, local communities, individuals and private firms:* Environmental-awareness programs on sustainable resources-management principles (both workshops and seminars, as well as public-service announcements on the radio and television, and the community theater).
- c. *Resource managers such as government- and private-sector employees and local communities:* Systematic formal training, based on country needs, through in-service training, in-country and overseas courses, and staff exchange among developing countries and between developing countries and developed countries.

Training priorities may include natural-resources assessment; development and implementation of environmental policies, regulations and standards; community-based natural-resources management; stakeholder communication; conflict prevention and management; sectoral environmental assessment; economic valuation of natural resources; and the use of market-based instruments in natural-resources management.

- d. *Resource users such as government agencies, local communities and the private sector:* Training on environmentally sound technologies and sustainable farming and fishing systems, as well as providing

information on alternative livelihoods that could reduce pressure on land and water resources and on microcredit schemes to facilitate the adoption of such livelihoods.

Strengthen Partnerships as a Means to Implement Priority Actions

The challenge of achieving food and environmental security is too great for one nation to tackle alone and, therefore, coordinated international efforts are needed. One of the positive lessons from the Green Revolution in the 1960s and 1970s is that partnerships involving a broad range of government and nongovernment stakeholders, including government and private research institutions, bilateral and multilateral development agencies, and foundations can play a major role in addressing the issue of food insecurity.

The Global Environmental Facility (GEF) is a partnership involving 10 international development agencies¹ that provides coordinated financial assistance to developing countries and others with economies in transition to address global environmental issues within the context of sustainable development. Its achievements during the last decade illustrate the importance and effectiveness of coordinated international financial and technical assistance.

Since 1991, the GEF has provided a total of US\$3.7 billion and leveraged, with the help of its partner agencies, governments, NGOs and others an additional US\$11.8 billion for activities addressing issues related to biodiversity conservation, climatic change, international waters, ozone-layer depletion, land degradation and persistent organic pollutants.

To help developing countries address issues related to integrated land and water management for food and environmental security, the GEF has provided more than US\$842 million and has leveraged an additional US\$1.7 billion in cofinancing for coordinated programs for integrated ecosystem management, management of national and international transboundary water bodies, and conservation of biodiversity of importance to agriculture.

Countries need to strengthen existing partnerships or create new ones, as needed, to provide an effective mechanism to achieve food and environmental security through integrated land and water management. The advantages of partnerships at the local, national and international levels include the following:

- a. *Improve coordination of funding:* Increased funding from public and private sources, including foundations, would be necessary to improve food and environmental security. Partnership arrangements can help mobilize adequate funds in a coordinated way from a variety of sources to address specific issues fully and effectively. These sources may include local and national budgets, bilateral development cooperation agreements, and country-assistance programs of multilateral agencies and foundations. Improved coordination would help avoid duplication of efforts as well as a piecemeal approach to addressing food- and environmental-security issues, which is less effective.
- b. *Improve leveraging opportunities:* Partnerships can help strengthen opportunities to leverage in-country policy and institutional reforms in support of integrated land and water management

¹UNDP, UNEP, the World Bank, the African Development Bank, the Asian Development Bank, the Inter-American Development Bank, the European Bank for Reconstruction and Development, FAO, UNIDO and IFAD.

because of the legitimacy, and financial and technical resources that a broad range of partners can bring to an issue.

- c. *Facilitate exchange of information and experiences:* Partnerships can help strengthen information exchange mechanisms, including clearing-house mechanisms that provide information on agricultural and environmental research. Through partnerships, countries can also have access to information and technical assistance on how to modify viable policy, regulatory and institutional models and management practices from both developed and developing countries to suit local conditions. Special emphasis should be placed on making information accessible not just to scientists but also to policymakers, resource managers and resource users.

- d. *Accelerate action-oriented research:* Research on analytical tools, management models, farming systems, and environmentally sound technologies on food and environmental security in different ecosystems can be accelerated significantly and better tailored to local needs through partnerships. For example, bringing together the expertise and infrastructure of international and national research centers, and the knowledge and experience of local policymakers and farmer associations can have a major impact on the pace, quality and relevance of research. Priority should be given to improving the infrastructure and capacity of national research centers in developing countries to make them effective partners in international efforts to address food and environmental security.

Development of Policies to Stimulate Food and Environmental Security: Priorities and Approaches

Assess, Update and Monitor Policy Priorities for Food Security

- Give a higher priority to marginal regions, even though many of these may be resource-poor. If sufficient area lends itself to sustainable agricultural intensification, then policy should promote yield increases that, at least, keep pace with population growth in these areas, within a landscape

perspective that recognizes environmentally important or sensitive resources. If not, agricultural support should be oriented more to protect household food security and local ecosystems and distinguish the different problems and interventions needed in lands with different quality and under different pressures. *Actors: departments of development planning, development banks,² NGOs.*

²Where a bank is mentioned, the involvement of an international development bank may also be effective.

- Establish land and water rights, especially for the poor. Stronger rights can provide security for poor people, and stimulate investments in appropriate management practices. *Actors: ministries of agriculture, environment; forestry departments, ministries of interior, smallholder groups.*
- Assess the extent of land and water degradation and food insecurity, with emphasis on hotspots at a subnational scale. This analysis should help both select options for food security that should not be sacrificed and quantify the impact on water supply, the environment and other biophysical and socioeconomic damage. Regional and global inventories are now inadequate and need to be updated. Information should be collected on resource degradation and on possibilities for conservation or local improvement. *Actors: national research systems,³ NGOs, local support groups.*
- Prepare regional policy and legal instruments to outline basic rules, standards and guidelines, to help achieve consistent approaches to the development of national natural-resources management policies and laws to manage and enhance food security. These regional instruments can, in relation to food security, include general ethical principles, sovereign rights, individual rights, state responsibilities, elements for national laws and policies, basic ecological standards, compliance measures, land planning and decision making, rights of access, compensation, environmental-impact assessment, capacity building and information sources, how to handle transboundary issues, types of institutions needed and measures/ methods for regional cooperation. *Actors: ministries of justice, agriculture, natural resources, national research systems, NGOs, farmer organizations.*
- Implement systems for monitoring the local status of land and water, linking participatory bottom-up assessments that reflect users' priorities with basin-wide and subnational indicators that can guide policy action and evaluate policy responses. *Actors: national resources management institutions, universities, NGOs.*
- At a national or regional level, use a basin perspective when designing changes that will affect land and water degradation: benefits at one scale may be neutral or disadvantageous at another. In the upper part of river basins, "catchments" should be seen as basic landscape units for land and water management. *Actors: national water boards, departments of irrigation and land development, national research systems.*
- Update national legal frameworks for the sustainable management of natural resources by utilizing the guidelines promoted by the Rio (Agenda 21) conference to guide resource users along sustainable pathways with minimal social conflict. For effective implementation, identify good possibilities for monitoring the state of

³Where a national research institution is mentioned, the support of an international institute may also be effective.

the natural resources. *Actors: ministries of natural resources, environment, agriculture, departments of justice, parliaments.*

- In situations of scarcity and competition, comanage water and land for agriculture and water and land for nature. Even though we have a sufficient understanding of agricultural water needs, there is little knowledge of the water requirements for natural ecosystems. *Actors: research institutes of the ministries for agriculture, natural resources and environment.*
- Improve the management of state-owned resources and facilities (including forests, rangelands, wetlands, irrigation systems) through institutional reforms and greater devolution to user groups. This applies particularly to the upland parts of river basins and to coastal areas, and to marginal areas in plains, and for irrigation systems mainly in plains and coastal areas. *Actors: ministries of environment, departments of forestry, irrigation, NGOs, rural people's organizations.*
- Focus on productivity of water in areas of water scarcity, as this will relieve scarcity, help the poor and may free up water for the environment and cities. *Actors: national research systems, departments of irrigation, water boards.*
- Focus on productivity of land in areas of land scarcity, as this will relieve scarcity, help the poor, and reduce pressure on marginal areas. High productivity without degradation is obtained by skillful management, and balanced use of fertilizer, water and appropriate varieties.

Actors: national research systems, ministries of agriculture, private sector.

- Pursue economic development through the stimulus of nonagricultural employment, particularly in areas with a marginal potential for agriculture from the point of view of natural resources. Promote methods to distinguish such marginal and nonmarginal areas. *Actors: ministries of planning and economic affairs, development banks, NGOs, rural entrepreneurs.*
- Intensify agriculture in areas with adequate biophysical potential for rain-fed agriculture through supplementary irrigation and fertilizers. This approach shows great potential for increasing the productivity of water and all other inputs, and hence for reducing poverty and enhancing local food security, provided all aspects of sustainability are taken on board. *Actors: ministries of agriculture, research and extension services, private sector, NGOs, farmer organizations.*
- Encourage the improvement of aquatic resource management in and around farmlands in a sustainable manner through appropriate legislation and information. *Actors: ministries of natural resources, agriculture, and fisheries.*

Improve National Capacity to Promote Effective and Equitable Land and Water Use, and Support Local Initiatives

- Enhance national capacity in extension, research and management of natural resources, using a capacity-building network approach with all relevant national and international partners, and

with emphasis on the creation of teams with a problem-solving orientation. There is a problem that structural adjustment by governments for extension services is declining, but these services can still facilitate and mobilize private action in land- and water-resource improvement. *Actors: national research and extension systems, ministries of agriculture, natural resources.*

- Promote education and training for designers and implementers of projects that influence land and water degradation. Part of the solution lies with university education, where more emphasis should be placed on holistic points of view, including integrated land- and water-resource management for food security. *Actors: training offices of the organizations concerned.*
- Produce a comprehensive assessment of the costs and benefits of irrigation in order to clarify the future directions for irrigated agriculture. Address the concerns associated with irrigation brought about by several nonagricultural stakeholders, especially those representing environmental interests. If we combine our scientific and indigenous knowledge and address the issues outlined above, we can reinvent the way we manage water for food, livelihoods, and the environment. *Actors: research institutes of the ministries of agriculture, livestock, fisheries, environment, farmer organizations, NGOs.*

Strengthen or Create Institutions to Plan and Manage Land and Water Resources at Basin and Landscape Scales That Enable Stakeholders to Participate More Fully

- Create innovative and more effective ways to bring existing knowledge to land and water users to accelerate significantly the pace of development of hundreds of millions of farmers, while reducing pressure on marginal areas and the environment. Further involvement of information technology holds great promise. *Actors: departments of extension, national research systems, NGOs, farmer organizations.*
- Integrate land and water management with agricultural productivity in extension services, emphasizing their contribution to increasing income, food security and local ecosystem services. *Actors: departments of extension, ministries of agriculture, natural resources.*
- Create institutional and technological innovations to allow groundwater irrigation and rainwater harvesting in a sustainable manner for the poor. *Actors: ministries of agriculture, NGOs, national research systems, extension services, private sector.*
- Develop effective sustainable institutional solutions to stop seawater intrusion in coastal areas. *Actors: national research systems, ministries of environment or natural resources.*

- Develop water-allocation procedures within river basins and within irrigation systems that encourage sustainable land- and water-conservation practices, whether they be market-based or through rationing of short supplies. *Actors: departments of interior, water boards, departments of irrigation, NGOs, farmer organizations.*
 - Include service provision to domestic users of agricultural water, in addition to irrigation, in new institutional frameworks—management structures and legislation. This will have a positive impact on people's health since water developed for agriculture is often an important domestic source for poor people. *Actors: irrigation agencies, public health, legislation branches.*
 - Create institutions that ensure accountability of water-service providers to users. The five most important institutional changes required are: replacement of administrative organizations with service-delivery ones; conversion of irrigation systems into multiuse water-service systems; transcending the infrastructure dependency/deterioration trap; establishing legal and regulatory frameworks for sustainable water management; and implementing integrated basin water management. *Actors: departments of interior, agriculture, fisheries, irrigation, water boards, NGOs, farmer organizations.*
 - Promote a service focus and reliability within irrigation system by building accountability mechanisms, by clarifying the level of service to be provided with the participation of service providers and users and by supporting acceptable and feasible designs. Improved irrigation services can raise the productivity of water, ease scarcity and promote environment-enhancing actions when the services are provided within the limitations and policies of a basin framework. *Actors: departments of irrigation, ministries of agriculture and natural resources.*
 - Develop a comprehensive institutional framework that provides for input and output water services in order to raise water productivity in agriculture. This national framework should address important issues, such as protecting access to water by the poor, water productivity, reducing pollution and groundwater overdraft and allocating water between competing sectors. *Actors: national research systems, ministries of agriculture, natural resources and environment, ministries of justice or interior.*
 - Build the capacity of local people's organizations to undertake local resource governance, taking care to promote women in them. Consider land- and water-quality impacts more explicitly in the design of new infrastructure. *Actors: ministries of justice or interior, NGOs.*
- Develop Mechanisms to Make Explicit the Value of Land and Water and to Provide Incentives for Resource Users and Investors***
- Resolve externality problems that arise when all or part of the consequences of environmental degradation are borne by people other than those who cause the problem (e.g., pollution of waterways and

siltation of reservoirs because of soil erosion in headwaters). Possible solutions include taxes on polluters and degraders, regulation, empowerment of local organizations and appropriate changes in property rights. *Actors: departments of economic affairs, ministries of agriculture, fisheries, environment, water boards, private-sector resource users and managers, watershed user organizations.*

- Correct price distortions that encourage excessive use of modern inputs in agriculture, that is, remove subsidies on fertilizers, pesticides, electricity and credit, and charge for water in proportion to water services provided, taking care to protect subsistence users and environmental uses. *Actors: ministries of economic affairs, agriculture.*
- Encourage the development of markets and appropriate supporting policies, e.g., water markets, where suitable, for more efficient allocation of water across uses and users. Land markets should discriminate according to land quality. Encourage the development of markets and transfer payments for watershed-protection services provided by users in the headwaters. *Actors: national and subnational legislative bodies, local entrepreneurs, NGOs.*

Develop and Disseminate Technologies and Resource-Management Practices to Improve Land and Water Management and Food Security

- Encourage more holistic approaches by paying more attention to the sustainability features of proposed

technologies, to broader aspects of natural resources management at the watershed and landscape levels and to better address poverty issues, all using more participatory methods. *Actors: national research systems; rural development and conservation programs.*

- Promote an adaptive management approach. Due to the endless diversity in land and water resources and the ways people use them in various countries, adaptation of recommendations is particular to each country and local situation. Unfortunately, good data to characterize the heterogeneity do not exist in most situations, so interventions may have to be carried out with first approximations from limited data sets and adapted by local users with research support. *Actors: agricultural research and extension services.*
- Use and further develop landscape planning tools that are participatory and facilitate negotiation among stakeholders. *Actors: planning and implementation agencies.*
- Undertake research to understand better how agro-ecosystems at landscape-scales produce their ecosystem services, and seek landscape-scale technologies and management practices that coproduce food and other services. *Actors: national research organizations, universities.*
- Promote research on, and implementation of, the large-scale recycling of nutrients in food and in waste, as continued transport from sources (rural areas) to sinks (cities, rivers) is unsustainable. Solutions are to be found at all levels: regulations,

technologies, markets and peri-urban production of high-value crops. The first step is to promote broader awareness of the problem. *Actors: city planners, universities, national research systems, private sector, ministries of education.*

- Promote small-scale recycling of nutrients in crop residues and livestock wastes. Nutrient recycling enhances soil conservation and C-sequestration.* Animal and fish production and use of manure, compost and wastewater for crops can be keys to recycling. Promote the identification of plant nutrient cycles. Solutions are to be found at all levels: regulations, technologies and markets. *Actors: national research systems, ministries of agriculture, livestock and fisheries, private sector, farmer organizations.*
- In intensive farming systems, promote a balanced nutrient supply to crops and soils, safe and sustainable methods of pest control, and halt genetic erosion within major food crops. Develop improved fallow systems for crop production on problem soils. *Actors: national research systems, ministries of agriculture.*
- Promote safe and cost-effective technologies and strategies for use of wastewater, based on realistic legislation and attainable standards. Ensure that the use of wastewater does not lead to transport of disease and buildup through improved hygiene, technological interventions and regulations, so that the positive effects on income and household

food security are not negated. *Actors: research institutes of the ministries for agriculture and public health, development banks.*

- Ensure that new sources of water for agriculture do not introduce waterborne diseases. Prevent the development of malaria and schistosomiasis in newly irrigated areas, which have, via human health, a strongly negative effect on household food security. *Actors: extension services, NGOs, private sector, national research systems.*
- Encourage the adoption of smallholder water-management systems. Rainwater harvesting, treadle pumps, bucket and drip sets, provide tremendous opportunities to help the poor and to increase the productivity of water. Success has already come from private and community-development efforts. *Actors: extension services, private sector, agricultural banks, NGOs, smallholders.*
- Find ways to increase income for local people from natural and perennial planted vegetation interspersed through crops and grazing lands, e.g., through agroforestry and non-timber forest products. Restore natural vegetation in landscape niches, such as riparian areas, where they can serve as landscape filters. *Actors: national research and extension organizations, farmer groups.*
- Share information on successful technologies and management strategies to reverse land and water⁴ degradation.

⁴The local action component of the Dialogue on Water, Food and Environment aims at providing this information exchange platform. Dialogue Secretariat, IWMI, Colombo, Sri Lanka.

There are many examples of successful solutions, often developed by local communities. Promote the exchange from farmer to farmer, resource manager to resource manager, through training, which can be most effective. Promote the sharing of information by specialist organizations, the lack of which hampers the ability of institutions to deal with land and water degradation and food security. *Actors: land and water managers at all levels: farmers, scientists, decision makers, NGOs.*

- Monitor for deficiencies of micronutrients in food and feed, particularly in the nutrition of vulnerable groups, as these deficiencies could severely reduce food security for children. *Actors: national health services.*
- Promote research on the stimulation of C-sequestration; desirable from the point of view of reducing climatic change; it is also a feature of land rehabilitation, particularly in humid and subhumid areas. *Actors: national research organizations, universities.*

Issues and Approaches in Research

Even though much knowledge has been collected about food and environmental security and particularly about land- and water-resources management, there are still important gaps that hinder the ability and potential capacity of scientists to assist policymakers and farmers. To increase this ability, key issues for research are identified in five areas:

- Improving food security.
- Mechanisms to alleviate poverty.
- Increasing ecosystem goods and services.
- Improved interactions between these areas.
- Legal frameworks to enable or facilitate change.

The approaches to better understanding and management of these issues can be characterized

by the terms “poor people focused,” referring to resource-poor persons and participatory research; “holistic,” referring to the integration of disciplines, scales and institutions; and “sustainability,” referring to long-term explorations. These terms are also captured in the umbrella concept of Integrated Natural Resource Management (INRM) (Sawyer and Campbell 2001).

Key Research Issues

Food Security

- How can land and water productivity be improved in fallow systems with problem soils when the fallow period is shortened (e.g., the introduction of legumes to restore soil fertility and limit weed invasion or through integration of crops and livestock to maximize benefits from such resources)? What is the best way to increase soil available phosphorus for leguminous species?

- How can rain-fed agriculture be intensified without increasing the hazards of off-site effects (pollution of the waterways, siltation, and eutrophication of the reservoirs,), e.g., a balanced nutrient supply, safe and sustainable methods of weed, disease and pest control?
- How can land productivity be improved in areas of low-quality or depleted soils, without causing soil degradation (e.g., agro-ecological practices based on soil cover and nutrient cycling, agroforestry)?
- How can water productivity be improved in areas of surface-water scarcity without causing land degradation (e.g., salinization) or introducing waterborne diseases (such as malaria), e.g., increased crop-water-use efficiency, water harvesting, and groundwater irrigation using treadle pumps, bucket and drip sets?
- In what specific ways does ecosystem health in the surrounding rural landscape (including water, non-cropland land use and natural vegetation resources) affect agricultural productivity in different types of agro-ecosystems, and what landscape features are especially important to conserve or enhance from a farming perspective?
- What is the current status of food insecurity at subregional, regional and global scales, and what are the trends?
- How can sustainable aquaculture be developed and improved at the farm level to improve protein availability?

- How can deficiencies of micronutrients be reduced in food and feed, particularly in the nutrition of vulnerable groups?

Poverty Reduction

- How do nonagricultural employment and income stimulate agriculture in marginal lands?
- What impacts do subsidies (on fertilizers, pesticides, electricity, water and credit) have on agricultural production and land and water degradation?
- What water rights and water markets/mechanisms can protect the rights of the poor and favor a more efficient and equal allocation of water across uses and users, and how can these be developed?
- What are the costs and benefits of irrigation for the rural and urban poor?
- What are the most appropriate water-allocation procedures within river basins and within irrigation systems that encourage sustainable land- and water-conservation practices?
- What are the conditions under which poor farmers invest for improved land and water management?
- How can the rate and efficiency of technology transfer to farming communities and between farmers be increased, using traditional and new methods?

- To what extent do the poor depend on natural vegetation in agro-ecosystems, and how can these resources be better protected and managed for their use?

Environmental Security: Ecosystem Goods and Services

- What are the impacts of land and water degradation on the services produced by agro-ecosystems at landscape, regional and global scales (e.g., deforestation in the headwaters,* loss of banded and riparian vegetation and degradation of the mangroves in the coastal zones)?
- How do agro-ecosystems produce their ecosystem services? What are the functions of landscape mosaics, patchiness and connectivity for the flows of water, sediments and nutrients? Where are the sources and the sinks, the corridors and the filters? Detailed mass balance studies are required to enable effective management.
- What are the critical threshold values for various characteristics beyond which agro-ecosystems are no longer resilient* (e.g., the minimum rootable soil depth below which no crops can grow, or minimum river discharges)?
- What is the current status of land and water degradation and resource improvement (e.g., updating of the regional and global inventories, with a clearer definition of indicators)?
- How will global change impact on ecosystem services (e.g., increase in wind and water erosion, seawater intrusion)?

- How can we design agricultural production systems that more closely mimic the natural ecosystem structure and function, while still supplying needed products?

- How can land rehabilitation through agro-ecological practices stimulate C-sequestration and contribute to the reduction of global warming?
- How can degraded lands and waters be turned into valuable land for alternative purposes: forestry, infrastructure (recreational facilities), nature conservation, parks and aquaculture?

Improved Interactions

- How can nutrients in food and waste transported from rural areas to cities and rivers be recycled on a large scale?
- How can off-site effects be internalized in production systems? Are there options for interbasin and inter-catchment transfer of incomes between upland farmers and water managers and city dwellers? How can users reward watershed-protection services in the headwaters?
- To what extent is government support required and effective on marginal lands to combat land and water degradation and improve land productivity?
- How can soil degradation issues related to C-sequestration and to regional or international transfers of nutrients in food and feed be included in global trade negotiations? How can water for

crop production be made an explicit part of international commodity-trade negotiations?

Legal Frameworks

- How do various forms of ownership and access to land and water affect attitudes and opportunities for sustainable agriculture?
- How can food and environmental security be defined at different scales for use in national legislative systems, to facilitate implementation and monitoring, and relate to international and regional frameworks?
- Develop context-specific “model” legal systems, so that countries can accelerate their own developments with these examples, and organize training at the national level to do so.

Key Research Approaches

- Priority to marginal regions and hotspots. Research should be focused on regions where the interactions between land and water degradation, food and environmental insecurity and poverty are the most pronounced.
- Holistic, people-centered research. Much of the research on resource management at the watershed and landscape levels, and on poverty issues in marginal areas needs to focus on the people, utilizing a gender perspective. It should be participatory, involving various stakeholders. The studies should include quantitative as well as qualitative methodologies for data gathering.

- Integrated research on crop and natural resources management should be framed from a multi-scale catchment perspective. Deriving results obtained from one small catchment located in the upper part of a river basin to a similar catchment is crucial. Upscaling of these results is possible provided that other processes are accounted for.
- Interdisciplinary research. A wide spectrum of disciplines needs to exchange approaches, from ecological sciences (e.g., soil science, plant ecology, hydrology) to management sciences (e.g. agronomy, hydronomy), socioeconomics and health sciences. Yet, interdisciplinarity requires contributions of sound mono-disciplinary knowledge.
- Interinstitutional research. The need for a continuum from strategic to applied research requires the involvement of various institutions and organizations: universities, advanced research institutions, international and national research centers, extension services, NGOs, and farmers’ and resource users’ organizations.
- Utilizing existing knowledge. In the information disseminated about successful technologies and management strategies to reverse land and water degradation (the “success stories”), there is a crucial need to distinguish generic knowledge from case-specific elements. Increasing the accessibility of existing information has great value.
- Long-term monitoring to detect changes. Long-term monitoring is essential to examine the effects of low-frequency events (e.g., severe droughts or very

heavy rainfall), and to determine threshold values of clearly defined indicators of land and water quality based on field assessment and remote-sensing observations. Even more than biophysical characteristics, socioeconomic characteristics are time-dependent. A data-clearing house needs to be established to oversee the quality and document the material provided from many sources, as well as the methods by which the values of indicators are determined and the procedures of sampling.

- Experiments to understand change processes. Ecological sciences and agricultural sciences cannot be based solely on monitoring. To learn about the

key processes, how they are controlled, and their on- and off-site effects, also requires experimental and manipulative approaches (e.g., paired experimental catchments with different agricultural practices).

- Models to simulate and predict changes. Based on existing, long-term monitoring and experimental data, and realistic scenarios of land-use and climatic changes, models enable the exploration of the consequences of land and water degradation or rehabilitation. Independently validated ecological, hydrological, land use, crop growth and socioeconomic models need to be coupled to predict interactions between ecological services, food security and poverty.

Glossary

Agricultural Plains, Lowland Plains or Plains. refer to the lower part of river basins, between the headwaters and the coastal area, excepting urban areas. They are mainly flat or rolling lands with large streams or rivers. In Asia and parts of Latin America, they typically contain large contiguous areas with rain-fed agriculture and irrigation systems. Huge areas are under low-intensity grazing or ranching in Latin America and Africa.

Agriculture. All human activities where natural resources are used to produce the raw materials for food, feed and fiber. Use of equipment, fertilizer and fossil energy in the process is common, and so is the use of irrigation water. Agriculture includes crop production, livestock production fisheries and timber. In most cases, the products are sold to markets.

Agro-ecological system. The total of the natural resources, the people and their interactions, in an area, where the processes within the system are (relatively) independent of those in other agro-ecological systems.

C (Carbon)-sequestration. The process by which carbon (C) from the air (in CO₂) is absorbed by growing plants and trees, and is left in dead plants (dead roots, exudates, mulch) in the soil. C-sequestration increases soil organic matter.* It counteracts buildup of CO₂ in the air and hence climatic change, and is also an aspect of land rehabilitation: the more C is retained in the soil, the better its fertility, water-holding capacity and resilience.

Coastal areas. The land area between the coast of the sea or the ocean and a line approximately 100 km inland, with all water bodies in it, plus the marine zone where most fisheries, aquaculture and tourism take place.

Degradation. In this report, degradation is defined as the sum of the processes that render land or water economically less valuable for agricultural production or for other ecosystem services. Continued degradation leads to zero or negative economic agricultural productivity. Degraded land and water can have a significant nonagricultural value, such as in nature reservations, recreational areas, and for houses and roads, even though for these purposes non-degraded lands are far superior. For more details, see Bridges et al. (2001). For loss of “land” in quantitative or qualitative ways, the term “degradation” is used. For water resources rendered unavailable for agricultural and nonagricultural uses, we employ the terms “depletion” and “pollution.” “Soil” degradation refers to the processes that reduce the capacity of the soil to support agriculture.

Desertification. A form of land degradation in which vegetation cannot reestablish itself after removal by harvesting, burning or grazing. It is due to overexploitation, and may occur in nearly every climate, but particularly in semiarid environments. Strong winds increase the vulnerability to desertification.

Devegetation. Removal of natural vegetation and crops that leaves the surface bare and exposed to degradation by water and wind erosion and leaching. Deforestation is the form of devegetation where trees and shrubs are removed. Reestablishment of plant and tree species in devegetated areas is often difficult because of harsh environmental conditions for germination and establishment. Grazing of

emerging plants can modify the vegetation composition significantly so that mainly unpalatable, weedy species are present in low density, rendering land unfit for agriculture. Devegetation can lead to desertification.

Ecological footprint. The virtual area cultivated or exploited to grow the crops and livestock, which supply the food that an average person consumes annually. Typically, this area is not contiguous, and part of this area may be far away, even in other countries. Its value ranges from 100 m² to 1 hectare, or even beyond these values, depending on the type of food consumed (vegetarian or rich in animal protein) and the productivity of the farming system (dependent on the intensity of management practices, and the quality of the natural resources). The size of the ecological footprint can be used to compare consequences of different lifestyles in different zones.

Ecosystem services refer to various benefits that ecosystems provide to people, including food, clean water, nature and wildlife, and also protection against natural disasters such as flooding. Agriculture is always part of an ecosystem, and agriculture can be seen as an ecosystem service.

Encroachment. People use land for agriculture in protected natural areas. While predominant in headwaters and coastal areas, it is also common in plains. The term refers to people moving on to new land, which happens when they have few alternatives for food production in unprotected areas. In other situations, people have been living in and cultivating the “encroached” area for a long time, albeit in smaller numbers, and the notion of protected area was recently imposed on them.

Environmental flow. The flow of water required to maintain healthy wetlands and other ecosystems.

Environmental security refers to the condition of natural resources in a particular area. Full environmental security is achieved when the resources provide full environmental services to the human beings who depend on this area and when this condition is sustainable. Rehabilitation of degraded areas to achieve this situation is only feasible if the damage threshold has not been exceeded.

Erosion refers to the process of movement of soil particles, with organic matter and nutrients contained in them, due to rain, water movement or wind. Erosion is accompanied by deposition nearby or at a distance. Erosion is a natural process that can be accelerated by soil cultivation or deforestation. Construction of infrastructure (roads, paths) can contribute much to accelerating erosion.

Evapotranspiration refers to the process by which water passes from the liquid state in soil and plants into a gaseous state in the air. Only the fraction that passes through plants can contribute to crop production.

Food security. In this report, this term indicates the production of food, the access to food and the utilization of food. For global food security, the emphasis is that sufficient food is produced in the world to meet the full requirements of all people: total global food supply equals the total global demand. For household food security, the focus is on the ability of households, urban and rural, to purchase or produce food they need for a healthy and active life; disposable income is a crucial issue. Women are typically gatekeepers of household food security. For national food security, the focus is

on sufficient food for all people in a nation; it can be assured through any combination of national production and food imports and exports. Food security always has components of production, access and utilization.

Globalization refers to the process by which more and more goods and services are traded internationally. It encompasses also greater commercialization of farming and more dependence on trade for achieving food security.

Grain equivalent. Our daily food has an endless variety of composition, water content, edible parts, and is produced from many crops. To express all in a single dimension, the term “grain equivalent” is used. It indicates by how much weight of grain (typically wheat) a certain amount of food could be replaced.

Groundwater is water extracted from the soil depth beyond the rooting zone, generally with manual or motorized pumps.

Groundwater depletion is the process of extraction of groundwater from below the rooting zone, sometimes from depths below 50 m, at a rate faster than groundwater recharge takes place.

Headwaters (or upland watersheds) refer to the upper parts of river basins where water is collected in small streams that merge into larger ones, and often flow into a reservoir or major river. Headwaters are typically hilly and mountainous areas, originally forested or covered with perennial vegetation, and in many cases the home of nature reservations. People in headwaters, sometimes living in tribes or other groupings of minorities, include the poorest people with often less formal rights than those downstream.

Heterogeneity and diversity. Both these terms refer to gradual changes in the nature and intensity of natural resources in space or in time, and to sociological and cultural diversity among the people living there. This natural phenomenon is the cause of problems and opportunities, but it makes effective management always highly site- and situation-specific. People at “peaks” can do very well. Poor people are generally found at the “troughs.”

Holistic and participatory approaches are successful approaches to reducing degradation and improving food security consider how to make the best use of, or to increase, all resources that people should have at their disposal: natural, human, physical, social and financial resources. Participatory means “with the people:” designing and implementing intervention strategies should occur together with all stakeholders.

Hotspots are the areas where the particular degradation problem is relatively intensive and significant. Bright spots are areas where various measures have led to halting degradation or even improving land or water quality or supply.

Land refers to all dry natural surfaces, and is generally vegetated for at least part of the year. Land is composed of different soil types combined in a particular landscape. Land use refers to the type of management; major categories are annual crops, perennial crops, fallows, pastures, herding on

rangeland, forest and conservation areas. Land quality refers to the capacity of the land to support agriculture, apart from the way it is managed.

Nutrient depletion (nutrient mining) refers to the process that slowly depletes the soil of its mineral constituents (mainly phosphorus [P], potassium [K], and nitrogen [N]). These are essential plant nutrients to crops. Depletion may take 5–50 years before the soil can no longer support economically sustainable cropping. The process is common on marginal soils where crop residues are not recycled. The nutrient balance, which assumes a negative value under depletion, refers to the difference of the inputs of nutrients into a farm (or catchment, region or country) from fertilizers, manure, biological N-fixation, rainfall) and the outputs (in crop harvests, leaching, erosion). Plants also absorb micro-nutrients (including Ca, Mg, Fe, Zn, Cu) in small quantities. Correction of the negative balance was long considered unnecessary, but micro-nutrient deficiencies are increasingly showing up in food crops and in human nutrition. Appropriate fertilizers can remediate this.

On-site effects, off-site effects. Effects are observed at the same location or area or beyond. Off-site effects are often not included in economic evaluations of practices.

Plains, lowland plains refer to the area downstream of headwaters, and upstream of coastal zones, and excluding the urban and peri-urban areas. Plains are usually flat and contain most of the agricultural activities.

Potential productivity. Biological production in conditions where inputs are not limiting and management is optimal. It is used as a reference value for the current level of productivity and “yield gap.”

Resilience. A property of complex ecosystems and society to withstand external pressure without significant internal change. Pressure beyond a threshold causes the system to collapse.

Salinization is the process of building up concentrations of salt in water or soil to levels that reduce or prevent crop growth.

Seawater intrusion is the process of seawater moving through the subsoil into the land. If it reaches the surface, salinization of soil and surface water occurs. The process occurs when freshwater near the coast is extracted from the soil.

Soil organic matter (SOM) comprises the remainder of plants and animals and microbes in the upper layers of the soil. It contains carbon (40%), nitrogen (0.1–1%), phosphorus, potassium and other plant micro-nutrients. SOM enhances the soil water-holding capacity.

Urban and peri-urban areas refer to those parts of the river basin where people and land and water management are strongly affected by large concentrations of people. This refers to cities with more than a few hundred thousand inhabitants, and particularly to mega-cities of several million persons plus the area with horticulture and animal husbandry that surround them. Most of these cities are in the lower parts of basins, often at or close to the coast. Important exceptions include the highland

cities of Mexico, the Andes, and the Himalayas. Peri-urban and urban agriculture (PUA) refers to very intensive, small- and large-scale agriculture, particularly horticulture, floriculture, poultry and pig production that occur in or near cities. It is characterized by its strong ties to urban life and markets, more so than by geography. PUA is a major consumer of city wastes (liquid and solid), but contributes to groundwater pollution and health hazards.

Wastewater is water from households and cities that has been used domestically, and that often contains urine and faeces of humans and animals, plus organic remainders of food preparations; wastewater may contain valuable plant nutrients, but is often also a carrier of diseases and heavy metals.

Water refers to all surface water in rivers, lakes, reservoirs, wetlands and aquifers. Water quality includes both the change in the availability of water (increases or reductions) in quantity, the contents of particles and dissolved materials, and contamination with diseases.

Water productivity is the quantity of produce, measured in weight or monetary terms per unit of water, and can be determined at the plot, farm, catchment and basin scale.

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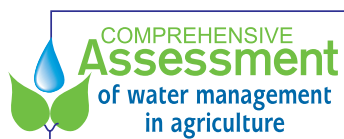
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Research Reports

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Postal Address: IWMI, P O Box 2075, Colombo, Sri Lanka **Location:** 127 Sunil Mawatha, Pelawatte, Battaramulla, Sri Lanka
Telephone: +94-11 2787404, 2784080 **Fax:** +94-11 2786854
Email: comp.assessment@cgiar.org **Website:** www.iwmi.org/assessment

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